LOCAL BUILDING CULTURES FOR SUSTAINABLE & RESILIENT HABITATS

EXAMPLES OF LOCAL GOOD PRACTICES AND TECHNICAL SOLUTIONS

A building culture results from the adaptation of a community to the environmental conditions of the territory in which it is established - physical, climatic, social, economic and cultural.

Communities have generally integrated local resources, climate and risks into their daily practices, developing their own strategies to cope with natural hazards and to enhance their habitat sustainability, durability and resilience.

To this end, local builders and populations have devised various measures, ranging from construction techniques and details, technical devices and temporary provisions, particular beliefs and specific behaviours at territorial, settlement and household levels.

These measures vary from hazard to hazard, from region to region, and have repeatedly demonstrated their relevance over time, during catastrophic events, and in relation to existing resources, constraints and capacities.

Taking these practices and technical solutions into consideration is extremely valuable for enhancing community and habitat resilience.

From:
"Assessing local building cultures for resilience and development. A practical guide for community-based assessment". CRAterre, IFRC, Caritas France, 2015.

Philippines: existing house (left) and houses rebuilt after the 2013 typhoon Haiyan with improved local techniques and materials

Philippines:
a rural house

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A typical house in Lefkada, Ionian Islands, Greece, with massive masonry ground floor walls and lighter and more flexible first floor walls

Preface

Poor housing is one of the major problems our world is still facing. Hundreds of millions are exposed to climatic, technological and human hazards in natural and built environments that are becoming increasingly vulnerable. Relevant solutions, sustainable and adapted to context, must imperatively be implemented to break this vicious circle and allow vulnerable populations to live, grow and build a future. Without this, a domino effect could amplify the damage, or even disrupt major balances and ecosystems, which could impact territories at a much wider scale, including areas that are supposedly "protected".

This global dimension should not make us forget to think and act locally: quite the opposite. As it was again highlighted at the 2015 Sendai UN World Conference on Disaster Risk Reduction, a special effort must be made to prevent, and so decrease, the impacts of natural hazards. Responses to crises and post-disaster situations also have to be improved and developed beyond the urgent and immediate needs of the affected populations, by taking into account the necessity to mitigate the effects of potential future hazards and to provide solutions in compliance with the principles of sustainable development. This perspective of resilience can only be achieved if it is based on the use of local capacities, resources and dynamics.

As a matter of fact, affected populations, professionals and local organizations cannot be mere aid recipients. It is local populations that truly hold the key to the sustainable improvement of their own resilience and living conditions. It is for this reason that local populations should be the main actors in (re)construction activities, and that such activities should prioritise and build upon their own capacities, knowledge and know-how.

It is in this regard that a number of humanitarian organizations recently came together to find alternative, context-adapted solutions. Although in some cases, the implementation of good technical solutions provided positive results, it became increasingly clear that in order to achieve proper sustainability in projects, the most important factor was not to find appropriate technical answers but to make use of, and fit with, local social, organizational, technical and financial capacities. The idea is clearly to work from what exists and to improve it while perpetuating endogenous capacities for adaptation and evolution and, most importantly to build on the local strengths and dynamics that accompany them. Many recent experiences on the field (Africa, Latin America, Caribbean, and Asia) have confirmed the relevance of such an approach.

Following several international seminars and, the 2010 publication of a manifesto titled *Promoting local building cultures to improve the efficiency of housing programmes*, CRAterre, the International Federation of Red Cross and Red Crescent Societies and Secours Catholique-Caritas France decided to go one step further. For this purpose, along the process more than hundred experts from around the world were invited to participate in this capitalization of experiences, to synthesize and theorize this type of approach. The idea was to develop tools complementary to existing ones, most particularly to the IFRC Participatory Approach for Safe Shelter Awareness (PASSA).

The first main result of this collective effort has been a handbook published in December 2015 entitled *Assessing local building Cultures for resilience and development, a practical guide for community based assessment* which was based on a PHD research (Caimi 2014). As a complement to this first product, this additional handbook that you are now holding provides information from all over the world as a tool for helping in the identification of local building cultures with high potential and also as references for helping reflection when exploring ways of addressing possible weaknesses in the existing local knowledge/practice.

We hope that this new tool will again contribute to collectively advance into a new level of improvement of the relevance of housing and construction projects. It is important that the organizations involved in the field share common references in order to ensure that existing local knowledge is valorised in shelter and settlements approaches in both preparedness and recovery efforts so that efficiency, durability, self-pride and hope can be generated towards improved resilience of local populations.

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[1] Full reference is available in appendix

Introduction

1. Overall framework

Hundreds of millions of people are living in built environments that are becoming increasingly vulnerable. Relevant solutions, sustainable and adapted to context, must imperatively be promoted to allow communities to thrive and build a resilient future. In most cases, the principal actors of the reconstruction are the affected population themselves. Thus, they can not be mere aid recipients as they are the ones that truly hold the key for the sustainable improvement of their own resilience and living conditions. From the very beginning, it is essential that projects enhance existing dynamics, by supporting people's capacities and knowledge. Past and on-going experience has proven that identifying, understanding, recognizing and, where needed, improving and strengthening local practices related to habitat and resilience is an extremely valuable approach for preparing efficient and relevant prevention and re-construction strategies.

Project summary

This document has been prepared in the framework of the research project *Methods and tools for the identification and promotion of local building cultures*, conducted by CRAterre and the LABEX AE&CC Architecture, Environment & Building Cultures

research unit from the Grenoble National School of Architecture, and supported by the Secours Catholique-Caritas France, the Shelter Research Unit together with the Shelter and Settlements department from the International Federation of Red Cross and Red Crescent Societies-IFRC.

This project is part of an initiative shared by partner institutions aiming to develop methodological and operational tools to foster awareness and appreciation on local building cultures and their relevance in improving ordinary construction practices and existing resilience capacities.

Within this project, the handbook *Assessing local building cultures for resilience and development. A practical guide for community-based assessment*, published in 2015, offers a tool for decision-making, planning and implementing programmes supporting local knowledge and resources in disaster risk reduction and habitat sectors. The complementary next step aims to share knowledge and to disseminate information on local building cultures, especially on those with high potential for responding efficiently and adequately to habitat improvement and vulnerability reduction needs.

Many local practices and technical solutions have already been identified in the field and during research projects by the CRAterre team as well as by other researchers and practitioners.

A PhD thesis developed at the CRAterre laboratory-University of Grenoble (2010-2014)[1] attempts to summarize a part of this information, proposing a base and ways forwards for a comprehensive and systemic approach to the identification, understanding and dissemination of local disaster-resilient constructions and practices.

Taking inspiration from this research, the present catalogue is a contribution towards a wider sharing and dissemination of knowledge and experience developed by local communities and builders. A lot of references still need to be collected, analyzed, understood, validated, summarized and disseminated. But we have to start somewhere and this document is a step forward on this path!

[1] CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience. Entre savoir, pratique et technique : appréhender le vernaculaire en tant que génie du lieu et génie parasinistre*. Grenoble: University of Grenoble.

Examples of local good practices & technical solutions

This document is the result of a 3-month exploratory phase aiming to create a dynamic and to broaden the scope of possibilities towards a better understanding and a wider dissemination of relevant measures and solutions developed by local communities regarding habitat and settlements.

It is a first base for an illustrated compilation of good practices and technical provisions with regard to sustainability, durability and resilience, identified within local building cultures of zones exposed to various constraints and types of natural hazards.

This catalogue is a complementary tool to the handbook *Assessing local building cultures for resilience and development. A practical guide for community-based assessment*. It offers examples of findings from field assessments. Some of the techniques and practices described would benefit from further research to be fully understood, especially the fact-sheets in which "Hypothesis" is mentionned in the title of the "vulnerability reduction" section.

1. Contents & data organization

This document presents 80 practices and technical solutions related to various types of natural hazards and issues concerning durability of habitat and settlements.
They refer to ways of building, construction systems and devices, coping strategies and community practices identified by some members of the CRAterre team over several years and during projects in different countries.
Data gathered from available documentation (thesis, reports, research projects, etc.) and directly from the CRAterre team members are summarized in thematic fact-sheets that can be organized and disseminated in several ways, including both printed and digital media.

Identified practices and solutions are classified according to the concerned construction parts, including also the surrounding environment that directly influences the safety and durability of the buildings:

- **FOUNDATION** ..... wall base, plinth, connection to the ground, etc.
- **MAIN STRUCTURE** ..... load-bearing systems: walls, frame, beams, etc.
- **ROOFING** ..... roof structure and covering
- **SECONDARY ELEMENTS** ..... openings, secondary structures, fences, etc.
- **ENVIRONMENT** ..... building surrounding, plot, settlement organization and location, etc.

This classification allows finding out a range of solutions and measures that can be useful to apply when designing a specific part of the construction. One or several measures can then be integrated into a single building design to improve its resilience, durability and adaptation to local constraints.

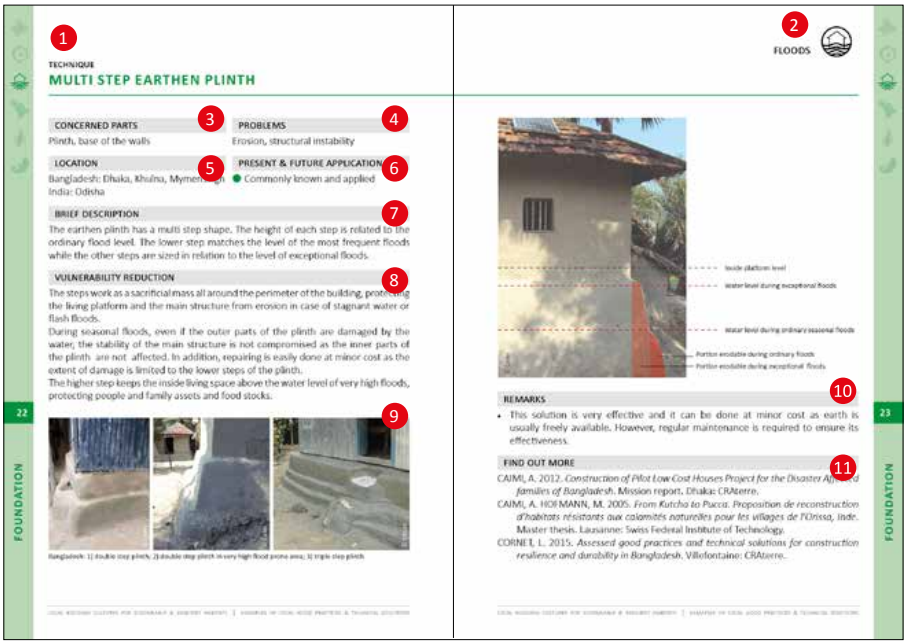
For each practice or technique, additional criteria are considered in relation to the geographical location, various natural hazards, present and future application. Thus, only measures related to specific criteria (for example, the type of natural hazard) can be selected. The considered criteria include:

- NATURAL HAZARDS / RISKS: earthquakes, cyclones, floods, landslides, soil erosion
  durability: maintenance, termites
- LOCATION: country, geographical region
- TYPE OF MEASURE: practice, technique
- APPLICATION OF THE PRACTICE / TECHNIQUE:
  commonly known and applied
  at risk- which may disappear
  not applied anymore

2. Fact-sheet structure

Each fact-sheet presents one of the identified practices or technical solutions.
The following pages are subdivided in 5 main sections – one for each concerned construction part - marked with different colours to ease identification.
The fact-sheets are listed at the beginning of each section.
They are organized using the following pattern:

1. Type of practice / technique
2. Natural hazards / risks
3. Concerned parts of the construction
4. Related problems to tackle
5. Countries, geographical regions
6. Present & future application
7. Brief description
8. Vulnerability reduction
9. Illustrations
10. Remarks
11. Resource materials



3. Warnings & limitations

Considering the huge number of practices, technical solutions and strategies developed by local builders and communities, this document clearly does not pretend to be comprehensive. Its main purpose is to give an insight into this wide variety and to offer some good practical references that could be relevant and helpful for stakeholders involved in habitat sector and disaster risk reduction activities.

In areas exposed to natural hazards, local building cultures often include many of the basic good practices recommended by current disaster engineering; such as 4-slope roof for better resistance to wind, horizontal seismic bands and bracing of the structural frame for earthquake protection, elevated site and/or raised building to reduce vulnerability to floods, etc.
For this document, the choice was made to focus mainly on those practices and technical solutions going beyond these basic principles. The cases presented in the following pages refer to methods and technologies specifically developed by local communities on the basis of existing resources and constraints and whose relevance has been demonstrated over time. Measures and approaches that are generally simple and relatively cheap to implement, presenting a high potential for responding efficiently and adequately to habitat improvement and vulnerability reduction needs.

The following thematic fact-sheets aim to illustrate construction principles and structural concepts on which each practice or technique relies, as well as to explain in a synthetic manner how it works and/or contributes in improving building resilience and durability.
These fact-sheets do not provide technical instructions or “receipts” to be applied, but a starting point for developing approaches and solutions taking inspiration from relevant knowledge developed by communities facing similar problems and constraints. For this reason, they do not provide detailed technical information regarding, for example, sizes, structural dimensioning, etc. These aspects have to be determined according to the specificities of each particular - physical, climatic, social, economical and cultural - setting.

Basic principles of disaster engineering integrated into local building cultures

Bangladesh: 1) The protective environment of an habitation: raised platform and tree barrier

Bangladesh: 2) & 3) Raised platform on braced stilts; post anchorage to the ground

Haiti: 4) Disconnection of main and secondary roof in a house rebuilt after 2010 earthquake; 5) hipped roof hipped roof and aerodynamic stocky shape of the building

Local building culture fact-sheets

FOUNDATION — 8 FACT-SHEETS


EARTHQUAKES


FLOODS


DURABILITY: MAINTENANCE

Geographical regions:
- Europe
- Central Asia
- South America
- South Asia
- Southeast Asia
- Middle East

MAIN STRUCTURE — 32 FACT-SHEETS


EARTHQUAKES


CYCLONES, STRONG WINDS


FLOODS


DURABILITY: MAINTENANCE

Geographical regions:
- Central Africa
- North Africa
- Central Asia
- South Asia
- Southeast Asia
- South America
- Caribbean
- Europe
- Middle East
- Oceania

ROOFING — 19 FACT-SHEETS


EARTHQUAKES


CYCLONES, STRONG WINDS


FLOODS


DURABILITY: MAINTENANCE


DURABILITY: TERMITES

Geographical regions:
- East Africa
- West Africa
- South Asia
- Southeast Asia
- Caribbean

SECONDARY ELEMENTS


EARTHQUAKES


CYCLONES, STRONG WINDS


FLOODS


DURABILITY: MAINTENANCE

13 FACT-SHEETS

GEOGRAPHICAL REGIONS:
- SOUTH ASIA
- SOUTHEAST ASIA
- CARIBBEAN
- MIDDLE EAST

ENVIRONMENT


EARTHQUAKES


CYCLONES, STRONG WINDS


FLOODS


DURABILITY: MAINTENANCE


LANDSLIDES, SOIL EROSION

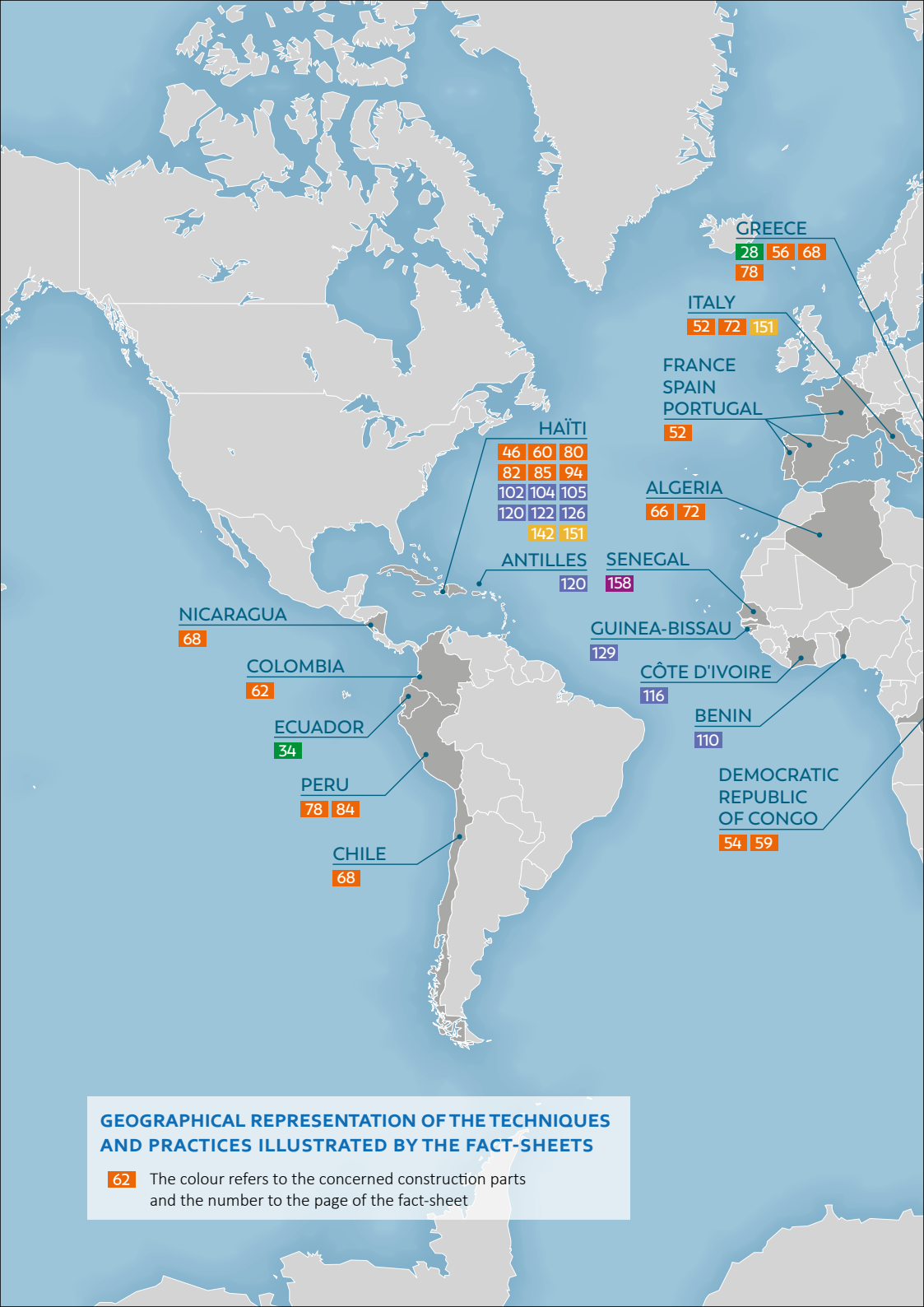
8 FACT-SHEETS

GEOGRAPHICAL REGIONS:
- CENTRAL ASIA
- SOUTH ASIA
- SOUTHEAST ASIA
- CARIBBEAN
- MIDDLE EAST

GRAPHIC EXPLANATION

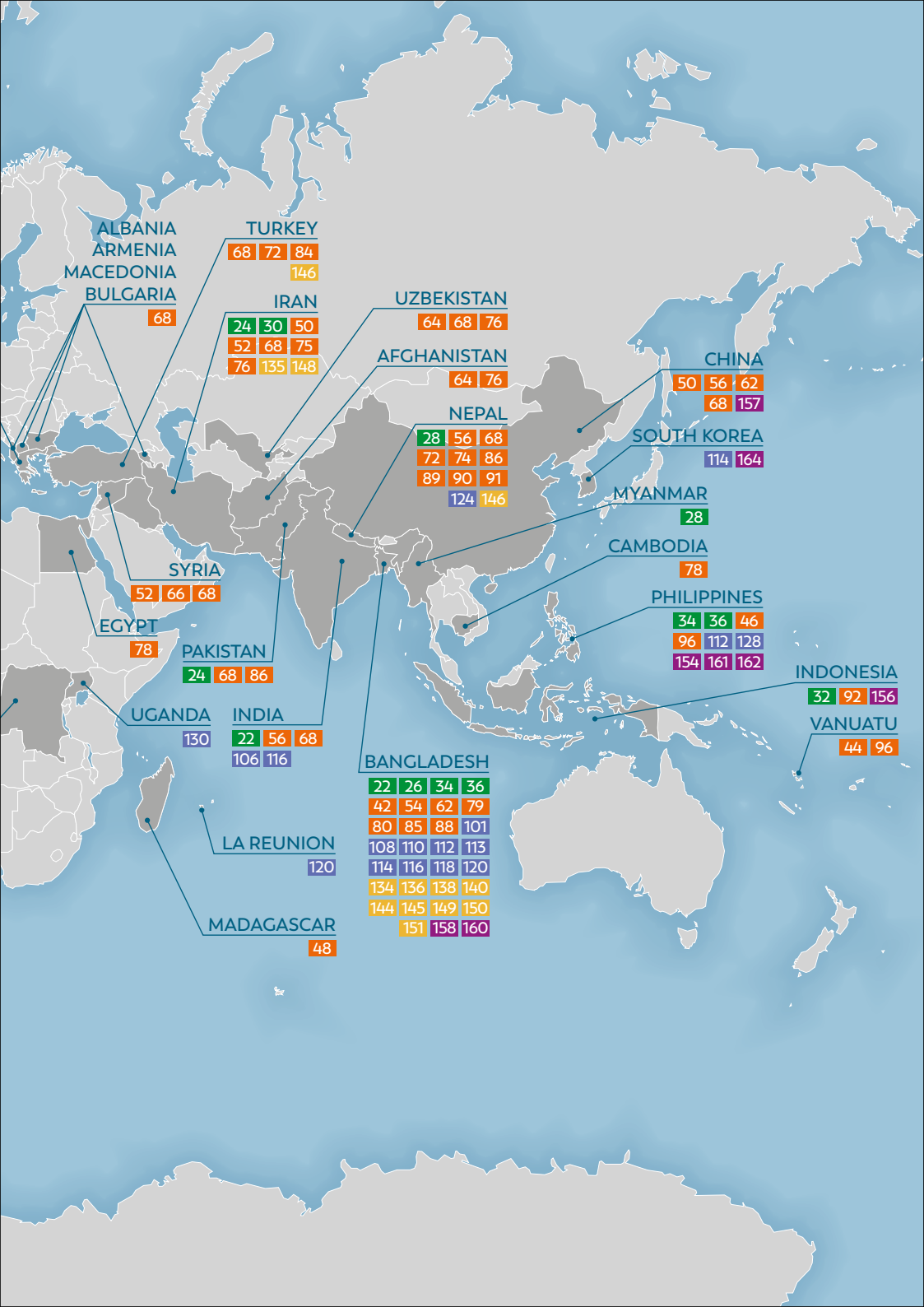
PRESENT & FUTURE APPLICATION

- PRACTICE / TECHNIQUE COMMONLY KNOWN & APPLIED
- AT RISK- PRACTICE / TECHNIQUE WHICH MAY DISAPPEAR
- PRACTICE / TECHNIQUE NOT APPLIED ANYMORE



GEOGRAPHICAL REPRESENTATION OF THE TECHNIQUES AND PRACTICES ILLUSTRATED BY THE FACT-SHEETS

62 The colour refers to the concerned construction parts and the number to the page of the fact-sheet


ALBANIA
ARMENIA
MACEDONIA
BULGARIA
68
TURKEY
68 72 84
146
IRAN
24 30 50
52 68 75
76 135 148
UZBEKISTAN
64 68 76
AFGHANISTAN
64 76
NEPAL
28 56 68
72 74 86
89 90 91
124 146
CHINA
50 56 62
68 157
SOUTH KOREA
114 164
MYANMAR
28
CAMBODIA
78
PHILIPPINES
34 36 46
96 112 128
154 161 162
INDONESIA
32 92 156
VANUATU
44 96
SYRIA
52 66 68
EGYPT
78
PAKISTAN
24 68 86
UGANDA
130
INDIA
22 56 68
106 116
BANGLADESH
22 26 34 36
42 54 62 79
80 85 88 101
108 110 112 113
114 116 118 120
134 136 138 140
144 145 149 150
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LA REUNION
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Bangladesh:
a rural house built on a platform

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FOUNDATION

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TECHNIQUE

MULTI STEP EARTHEN PLINTH

CONCERNED PARTS	PROBLEMS
Plinth, base of the walls	Erosion, structural instability

LOCATION	PRESENT & FUTURE APPLICATION
Bangladesh: Dhaka, Khulna, Mymensingh India: Odisha	● Commonly known and applied

BRIEF DESCRIPTION

The earthen plinth has a multi step shape. The height of each step is related to the ordinary flood level. The lower step matches the level of the most frequent floods while the other steps are sized in relation to the level of exceptional floods.

VULNERABILITY REDUCTION

The steps work as a sacrificial mass all around the perimeter of the building, protecting the living platform and the main structure from erosion in case of stagnant water or flash floods.

During seasonal floods, even if the outer parts of the plinth are damaged by the water, the stability of the main structure is not compromised as the inner parts of the plinth are not affected. In addition, repairing is easily done at minor cost as the extent of damage is limited to the lower steps of the plinth.

The higher step keeps the inside living space above the water level of very high floods, protecting people, family assets and food stocks.

Bangladesh: 1) double step plinth; 2) double step plinth in very high flood prone area; 3) triple step plinth

REMARKS

- This solution is very effective and it can be done at minor cost as earth is usually freely available. However, regular maintenance is required to ensure its effectiveness.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CAIMI, A. HOFMANN, M. 2005. *From Kutcha to Pucca. Proposition de reconstruction d'habitats résistants aux calamités naturelles pour les villages de l'Orissa, Inde*. Master thesis. Lausanne: Swiss Federal Institute of Technology.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

TECHNIQUE

WATER RESISTANT LAYER ON A WALL FRONT FACE

CONCERNED PARTS

Foundation, base of the walls

PROBLEMS

Erosion and weakening of the wall due to water stagnation

LOCATION

Iran: Yazd
Pakistan: Sindh

PRESENT & FUTURE APPLICATION

● At risk

BRIEF DESCRIPTION

Fired bricks are used for the bottom part of earthen walls according to different techniques:
- simple cladding on the outside of the wall;
- mixed masonry base on the front face of the wall and sun dried bricks on the inside face;
- full masonry plinth under sun dried brick walls.

VULNERABILITY REDUCTION

Fired bricks have a better resistance to water than sun dried bricks. Protection of the more exposed parts (foundation and/or lower portion of the wall) improves the capacity of the overall building to withstand during floods. It prevents loss of structural stability due to a weakening of the earthen wall caused by standing water and water erosion. In mixed masonry base, interlocking of the two sides every 5 layers ensures a connection between the two wall faces, preventing delamination.

Iran: 1) brick cladding on outside wall

Pakistan: 2) interlocked fired bricks on the front face of a sun dried masonry wall; 3) full fired brick plinth under earthen wall

REMARKS

- The three applications range from the less to the most effective as well as from the cheapest to the most costly one. However, the use of fired bricks is optimized for very specific and localized parts keeping the cost very limited.

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience.* PhD Thesis. Grenoble: University of Grenoble.

UN-HABITAT Pakistan. 2010. *Monsoon flood 2010 Pakistan. Rapid Technical Assessment of Damage and Needs for Reconstruction in Housing Sector*. Islamabad : UN-HABITAT.

CRÉTÉ, E. 2016. *L'architecture en terre crue face aux catastrophes : oubli des stratégies traditionnelles et enjeux en période de reconstruction*. Mémoire du DSA Terre. Grenoble: École Nationale Supérieure d'Architecture de Grenoble

PRACTICE

PLINTH PROTECTION WITH STONES

CONCERNED PARTS	PROBLEMS
Plinth, base of the walls	Water stagnation, plinth erosion
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Sylhet	● Commonly known and applied

BRIEF DESCRIPTION

Stones are laid all around the building at the bottom of the earthen plinth and under the roof line.

VULNERABILITY REDUCTION

Stone perimeter protects the earthen plinth and the surrounding ground from erosion. In addition, when connected to an evacuation, it provides drainage for water falling from the roof thus avoiding water stagnation and preventing rising damp.

Bangladesh: 1) stone protection on the front of the house

REMARKS

- This practice uses freely available stones and it does not require particular skills. However a regular maintenance is necessary to ensure its effectiveness.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

Bangladesh, stones placed: 2) all around the building and 3) under the roof line

TECHNIQUE

DISSIPATIVE PLATFORM

CONCERNED PARTS	PROBLEMS
Foundation	Ground movements

LOCATION	PRESENT & FUTURE APPLICATION
Greece: Delphi temple Myanmar: Bagan Nepal: Kathmandu	● Not applied anymore

BRIEF DESCRIPTION

Major buildings are built on a specific platform that is made out of sand mixed with lime, small stones and broken bricks. The over ground parts of the platform are enclosed by massive stones or brickwork.

Myanmar, Bagan: 1) a partly over ground platform at Dhammayangyi temple, 2) the eroded core of an ancient platform is nowadays exposed at Dhammayangyi temple

VULNERABILITY REDUCTION / HYPOTHESIS

The enclosed materials allow for a dissipation of energy due to friction and acts as a seismic base isolator.

Nepal, Kathmandu: 3) a temple platform that may have a dissipative function

FIND OUT MORE

BILLARD, A. 2014. *Risque sismique et patrimoine bâti: comment réduire la vulnérabilité : savoirs et savoir-faire*. Paris; La Plaine Saint Denis : AFNOR Éditions, Eyrolles.

CRÉTÉ, E. 2016. *First Aid to Cultural Heritage in Bagan Archaeological Area*. Mission report. ICCROM / UNESCO.

TECHNIQUE

LOG PILES AS SEISMIC ISOLATOR

CONCERNED PARTS

Foundation

LOCATION

Iran: Gilan province

PROBLEMS

Horizontal displacements, ground/structure differential movements, ground moisture

PRESENT & FUTURE APPLICATION

● At risk

BRIEF DESCRIPTION

Timber frame houses are elevated on a 40 to 60 cm-high platform supported by piles of short and roughly squared logs. The pieces of wood are simply stacked without fixation. Each layer is oriented perpendicularly to the previous one and the number of logs gradually decreases to the top of the pile.

VULNERABILITY REDUCTION

During earthquakes, the log piles act as seismic isolators and friction dampers enabling a considerable dissipation of seismic energy thanks to the rolling of the logs one over the other and to the movement of the whole building.
The displacement of the logs considerably reduces the horizontal movements transmitted to the platform and the structure.

Iran: 1) traditional house on elevated platform; 2) log piles supporting the platform

REMARKS

- In addition, the elevated platform preserves the main structure from ground moisture, improving the overall lifespan of the building.
- During past earthquakes, this technique demonstrated its relevance: in some cases the superstructure showed a displacement of more than 20cm without any damage.
- Under the piles of logs, holes are excavated and filled with ashes and wood charcoal to reduce rising damp from the ground.

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

NADERZADEH, A. 2009. «Application of seismic base isolation technology in Iran». In : *Menshin Journal*. n° 63, p. 40-47.

Iran: 3) timber frame house elevated on a platform; 4) detail of log piles

TECHNIQUE

BASE ISOLATION FOR STRUCTURAL FRAME

CONCERNED PARTS	PROBLEMS
Foundation	Horizontal displacements
LOCATION	**PRESENT & FUTURE APPLICATION**
Indonesia: Aceh, Nias Islands, Sumatera Utara	● At risk

BRIEF DESCRIPTION

The structural frame lies on flat stones placed directly on the ground. No connection or fixation system is used between the timber posts and the stone slabs.

VULNERABILITY REDUCTION

The superstructure is decoupled from the foundations thanks to their structural disconnection. Movement and minor sliding of the posts on the foundation stones occur frequently, reducing the seismic loads and internal stresses in the structure.

Indonesia: 1) structural frame on stone bases; 2) sliding of diagonal bracing on stone foundation during 2005 M 8.6 earthquake

A piece of jute or a layer of reeds is sometimes placed between the posts and the stones. It thus increases the friction between the foundation and the superstructure, and facilitates seismic energy dissipation.

REMARKS

- The stones protect the timber posts from rotting due to ground moisture.

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

GRUBER, P. 2007. *Adaptation and Earthquake Resistance of Traditional Nias Architecture*. Wien: Institute for Comparative Research in Architecture - Institute for History and Research of Building.

Indonesia: 3) layer of reeds placed between the stone base and the timber post

TECHNIQUE

SACRIFICIAL POST

CONCERNED PARTS

Base of the posts

PROBLEMS

Rotting, loss of structural stability

LOCATION

Bangladesh: Barisal, Chittagong, Mymensingh
Ecuador: Costa region
Philippines: Aklan Province

PRESENT & FUTURE APPLICATION

● Commonly known and applied

BRIEF DESCRIPTION

The structural frame relies on short separated posts driven into the ground.

VULNERABILITY REDUCTION

The short posts anchor the building to the ground while keeping the main structure elevated and so protected from soil moisture. When damaged, the short posts driven into the ground (fuse) can be easily replaced without affecting the superstructure.

Bangladesh, different materials and connections between the main structure and the fuse posts:
1) bamboo and iron wire; 2 & 3) special carving to connect timber posts in the same plane
Philippines: 4) rattan tying to improve the connection between the main structure and the fuse post

REMARKS

- Replacement of the damaged lower posts can be done at minor cost as only a short piece of wood is needed.
- A hard and long-lasting timber is often used for the lower posts to increase their durability.
- Shorter posts are needed for the superstructure.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CAIMI, A. 2015. *Shelter and livelihood improvement project for the indigenous community of Aklan. recovery after typhoon Yolanda*. Mission report. July 2015. Kalibo: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

SEVILLANO GUTIERREZ, E. 2017. *Ecuador, Costa - Culturas constructivas locales para el desarrollo y la resiliencia.* Grenoble: IFRC, CRAterre

TECHNIQUE

POST ISOLATION FROM THE GROUND

CONCERNED PARTS	PROBLEMS
Base of the posts	Rotting, loss of structural stability
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Barisal, Rajshahi Philippines: Aklan Province	● Commonly known and applied

BRIEF DESCRIPTION

The timber posts rely on one or more stacked waterproof elements.

VULNERABILITY REDUCTION

The posts are raised up from the ground so that they are not in contact with soil moisture. This technique increases the structure durability by preventing posts rotting.

Philippines: 1) stone base under a post of a stilt house
Bangladesh: 2) isolation with a pile of waterproof elements and (3) with a simple brick

REMARKS

- This system is used for both stilt and on-the-ground houses.
- Low-cost locally available materials (such as stones, burnt bricks or small concrete elements) are generally used for waterproofing.
- In cyclone prone areas, the isolation is used mainly for the intermediary posts while the corner posts are driven directly into the ground or provided with foundation to ensure sufficient stability and anchorage of the building.

FIND OUT MORE

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Haiti:
a rural house built after 2010 earthquake

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PRACTICE

DEMOUNTABLE LIGHTWEIGHT HOUSE

CONCERNED PARTS	PROBLEMS
Structural frame, roof, fences	High water level
LOCATION	**CURRENT & FUTURE APPLICATION**
Bangladesh: Dinajpur	● Commonly known and applied

BRIEF DESCRIPTION

Houses are designed to be quickly and easily dismantled, moved and reassembled by the inhabitants themselves.

VULNERABILITY REDUCTION

During exceptional high floods, people dismantle their houses and temporarily move them to a safer place (embankment, inland).
Lightweight materials (such as iron sheets for roofing and woven mats for fences) are used to form panels that can be moved in one whole piece as well as particular joints that can be open very quickly and reused.
A fast recovery is then possible as the materials of the house are preserved and can be easily reused.

Bangladesh: 1) houses in normal time; 2) connection of the roof structure to the posts, the stick can be quickly removed and replaced so that the joint can be opened and closed several times using the same components

REMARKS

- During floods, the house is partially or totally rebuilt on a safer place and used as emergency shelter.
- This practice is a very effective and relatively low-cost solution for people living in a region where every 2-3 years the water level reaches 2 or 3m height and riverbanks are affected by important erosion.

FIND OUT MORE

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Bangladesh: 3) house displacement by parts during high floods

PRACTICE

CYCLONE-PROOF COMMUNITY SHELTER

CONCERNED PARTS	PROBLEMS
Structural frame	Sheltering during cyclones
LOCATION	**CURRENT & FUTURE APPLICATION**
Vanuatu	● Commonly known and applied

BRIEF DESCRIPTION

Rectangular or circular shape constructions built with local natural materials (such as bamboo, wood, sugarcane, banana and coconut leaves) are traditionally used as collective evacuation centres to accommodate 40 to 60 persons during cyclones.

VULNERABILITY REDUCTION

The shelter is generally located on a site naturally protected from strong winds and placed in the middle of a settlement, so that the surrounding buildings break the wind flow thus reducing the cyclone impact on the shelter.
The low height and the extension of the roof almost to the ground provide improved aerodynamism to the building, sometimes enhanced by the shelter round shape.
During a cyclone, people inside the shelter hang to the structure thus loading it with all their weight and reducing the risk of roof blowing off.

Vanuatu, cyclone shelters: 1) with walls and elevated roof and 2) circular aerodynamic shape with a roof extended to the ground

REMARKS

- The size of the shelter generally depends on the size of locally available materials to avoid connexions between structural elements as they may break in case of winds.
- A large number of cyclone shelters are generally available as each extended family has its own shelter built nearby the houses. This ensures a quick and easy access as the distance to reach them in case of cyclone is limited.

3) people holding the structure during cyclones

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PRACTICE

CYCLONE & EMERGENCY SHELTERS

CONCERNED PARTS

Structural frame

PROBLEMS

Sheltering during and after cyclones

LOCATION

Haiti: West department
Philippines: Aklan province

CURRENT & FUTURE APPLICATION

● Commonly known and applied

BRIEF DESCRIPTION

Low-rise constructions with rectangular plan built using local natural materials (such as bamboo, straw, sugarcane, banana and coconut leaves) are traditionally used as family shelter during and after cyclones.

VULNERABILITY REDUCTION

The shelters are built on an open site protected from falling trees or other debris. In Philippines, they are often located faraway from the main house, on the slopes of the mountain to avoid flash floods that may occur in the valleys. In Haiti, they are usually built close to the main house and are used as kitchens in normal times.

Philippines: 1) shelter used as temporary living place after 2013 typhoon Haiyan

When a cyclone is announced, people collect their goods and move to the shelters to be protected from the possible partial or total collapse of the house and other risks caused by strong winds and heavy rain. Once the cyclone is over, the shelter is used as a temporary living place during the house repairing or reconstruction.

The very low height (in some cases, it is hardly possible to stand inside) and the roof extended to the ground provide improved aerodynamism to the building reducing the impact of strong winds.

Haiti: 2) straw shelter

REMARKS

- When used as kitchen in normal times, the smoke of the fire for cooking helps increasing the lifespan of the construction by reducing insect attacks.
- This practice is applied and very effective especially in remote areas where accessibility to community shelters is often impossible during heavy rains and where settlements are scattered on a large area.

FIND OUT MORE

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PRACTICE

DEMOUNTABLE WALL PANELS AND ROOF

CONCERNED PARTS	PROBLEMS
Walls and roof panels	Sheltering during cyclones, walls collapse, roof blowing off
LOCATION	**CURRENT & FUTURE APPLICATION**
Madagascar: Sambava, Antalaha	● Commonly known and applied

BRIEF DESCRIPTION

Before a cyclone, people remove roof and wall panels from the house frame, putting them on the ground. After the cyclone roofs and wall panels are put back on the frame and damaged elements are replaced.

VULNERABILITY REDUCTION

Roof and wall materials are removed in order to safeguard the materials and to provide a shelter. The house frame is not dismantled but is less affected by winds thanks to its reduced wind surface area. In many cases the roof is then used to make a low level A-frame shelter under which people can survive the cyclone.

Madagascar: 1) roof and wall panels are fixed with vegetable ties that allow for a frequent and quick dismantling without damaging the materials; 2) a roof that was dismantled and used as a temporary shelter during 2017 cyclone Enawo

REMARKS

- Ability to make this adaptation depends on age of the materials – older materials will less likely be reusable.
- Given that many households have multiple structures, only one or two structures are dismantled.

FIND OUT MORE

IOM, 2017. *Rapid shelter assessment report Sambava and Antalaha.*

Madagascar: 3) example of a family grouping of houses: the frame of a house that was dismantled is in the back (left) with the roof that was used as a temporary shelter (centre back)

TECHNIQUE

UNDERGROUND DWELLINGS

CONCERNED PARTS

Main structure

PROBLEMS

Wall collapse

LOCATION

Iran: Yazd, Bam
China: Gansu, Lanzhou, Henan, Shanxi, Hebei

CURRENT & FUTURE APPLICATION

● Not applied anymore

BRIEF DESCRIPTION

Houses are partly or totally excavated from cliffs or from flat terrain. In the latter case, the main rooms often surround a courtyard.

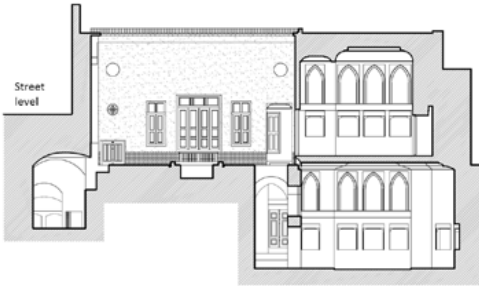
VULNERABILITY REDUCTION

In case of a quake, partly buried buildings usually suffer less damage as a lowered gravity center allows for a reduction of shearing stresses at the base of the building. Moreover, underground spaces benefit from ground stiffness.

REMARKS

- In China (Hebei province), it was noticed after 1976 earthquake that underground dwellings behaved far better than above ground buildings.
- When built over a basement, a wall is no longer embedded into the ground but articulated at both ends. Its stiffness is significantly reduced. Hence, it is important to keep structures built over basement low in order to warranty a good global behaviour in case of a quake.
- Building a construction partially or totally underground offers further advantages:
  - the excavated soil may be used to produce the superstructure;
  - it can help reaching a ground that is strong enough to bear the building weight;
  - in Iran, it allows for some of the houses to benefit from direct access to underground water channels, called *qanat*;
  - underground spaces benefit from the ground thermal inertia which keeps the rooms relatively warm in winter and cool in summer.

1) China: underground dwelling



2) Iran: section of a Qajar house in Yazd

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TECHNIQUE

COUNTER ARCHES BETWEEN BUILDINGS

CONCERNED PARTS

Walls

PROBLEMS

Wall collapse

LOCATION

France: Corsica, Alpes-Côte d'Azur Province
Iran: Yazd
Italy: Campania, Liguria, Sicily
Portugal: Alentejo, Evora
Spain: Andalusia
Syria: Damascus, Alep

CURRENT & FUTURE APPLICATION

● Not applied anymore

BRIEF DESCRIPTION

Masonry arches connect two separated buildings.

VULNERABILITY REDUCTION

During earthquakes, the horizontal forces are transmitted from one building to another through the arches. They create continuity between stand-alone buildings and/or separated built blocks that do not longer work as isolated elements but as dynamic blocks, benefiting from the total mass of several buildings to counteract lateral seismic loads and reducing the risk of overthrow of façades.

Counter arches: 1) France, Bonifacio; Italy: 2) Palermo and 3) Atrani

4) Iran: Counter arches in Yazd

REMARKS

- The arches endpoints may be at different heights corresponding to the floor levels of the connected buildings.
- This system works very well with stone masonry arches as they allow for a certain flexibility thus avoiding punching-effects that may occur with more rigid materials (such as concrete).
- In case the arches are destroyed, the buildings are no longer structurally connected and the whole block may be endangered in case of a quake.

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TECHNIQUE

INDEPENDENT ROOF STRUCTURE

CONCERNED PARTS	PROBLEMS
Walls, structural frame	Wall collapse
LOCATION	**CURRENT & FUTURE APPLICATION**
Bangladesh: Chittagong, Mymensingh, Sylhet Democratic Republic of Congo: Kabalo	● At risk

BRIEF DESCRIPTION

The roof structure is borne by an independent timber or bamboo frame while the inside space is fenced by non-load bearing earthen walls. The posts may be indoors or outdoors.

VULNERABILITY REDUCTION

In case of damage to the walls during floods or earthquakes, the risk of a complete collapse of the building is reduced thanks to the structural separation between the roof bearing structure and non-load bearing walls. The frame can withstand autonomously, hence preserving the roof which is often the most expensive part of the construction.

1) Democratic Republic of Congo: outdoor post structure bearing a 4-slope roof

REMARKS

- Repairing works can be easily carried out at minor cost and the space under the withstanding roof can be used as emergency shelter.
- The roof widely covers the walls, ensuring thermal comfort and protection from rainwater.

FIND OUT MORE

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Bangladesh: 2) after flooding, people keep on living inside the house even if the back walls have been damaged;
3) half earthen wall with indoor independent structure for the roof

TECHNIQUE

DOUBLE LOAD-BEARING SYSTEM

CONCERNED PARTS

Structural frame

PROBLEMS

Collapse of main load-bearing system

LOCATION

China: Lijang, Shangrila
Greece: Lefkada Island
India: Maharastra
Nepal

CURRENT & FUTURE APPLICATION

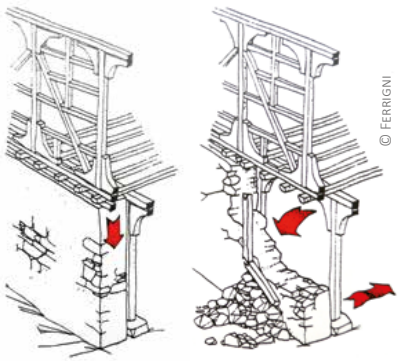
● At risk

BRIEF DESCRIPTION

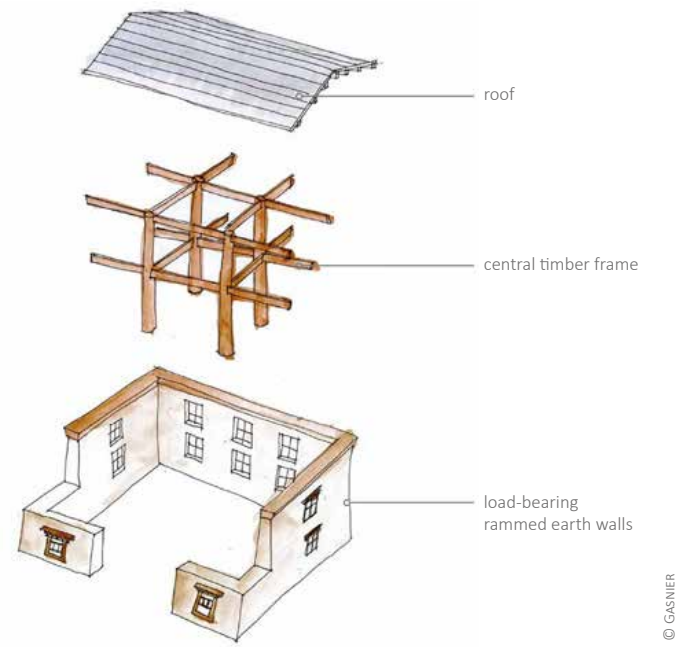
Stone masonry walls are doubled by an inside timber frame.

VULNERABILITY REDUCTION

In ordinary situation, the main structural loads are carried by masonry walls.
In case of partial or total failure of the masonry walls during an earthquake, the timber frame takes over carrying the load of the upper stories and the roof. The risk of a collapse of the whole building is thus limited. As the floors stand even in case of wall collapse, occupants have more time to escape from the building.



Greece, Lefkada Island: 1) inside timber frame; 2) behaviour of the double load-bearing system a) in ordinary situation and b) in case of an earthquake



China: 3) structural system of 4) traditional house in Shangri La

5) India, Maharastra: one storey structure after the 1993 earthquake;
6) Nepal, 2-storey buildings: inside frame after 2015 Gorkha earthquake

REMARKS

- A gap is generally left between the two load-bearing systems to ensure their independent behaviour and to limit damage caused by pounding during earthquakes.
- In some cases, the upper stories are built with a timber frame structure behaving as a light and flexible box during earthquakes.
- In case of wall failures, the frame placed on the inside prevents the inwards collapse of the masonry reducing risk of injuries for the inhabitants.
- After an earthquake, the masonry walls can be rebuilt or repaired reusing the stones from the previous walls and without affecting the stability of the building.
- The building can continue to be used during reconstruction/repair providing on-site shelter.

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TECHNIQUE

FRAME REINFORCEMENT FOR MASONRY WALLS

CONCERNED PARTS	PROBLEMS
Load-bearing masonry walls	Dissociation of perpendicular walls
LOCATION	**CURRENT & FUTURE APPLICATION**
Democratic Republic of Congo: Kabalo	● At risk

BRIEF DESCRIPTION

The corners of the building, the bottom parts of the walls and the portions around the doors are strengthened by an increased thickness of the masonry wall. Enlarged plinth and beams connect these pillars.

VULNERABILITY REDUCTION

Providing an additional mass, the reinforcement improves the capacity of the building to better resist to later forces and reduces the risk of a disassociation of perpendicular walls in case of earthquake.

Democratic Republic of Congo: reinforcement on earthen masonry walls

FIND OUT MORE

MOLES, O. HOSTA, J. 2009. *Sensibilisation aux système constructifs adaptés à la région de Kabalo, République Démocratique du Congo*. Grenoble: CRAterre.

TECHNIQUE

SHARP ANGLE CORNER REINFORCEMENT

CONCERNED PARTS	PROBLEMS
Walls	Dissociation of perpendicular walls Structural failure
LOCATION	**CURRENT & FUTURE APPLICATION**
Haiti: South-East department	● Commonly known and applied

BRIEF DESCRIPTION

The corners of the building are reinforced with an increased thickness of the masonry following a sharp angle shape.

VULNERABILITY REDUCTION

The reinforcements provide additional stability and stiffness to the structure which is better able to withstand lateral loads during earthquakes and cyclones. The triangular shape gives a certain degree of aerodynamic to the building, breaking the wind flow at the corners and so reducing its impact on the structure.

Haiti, sharp corner reinforcement: 1) view on the building and 2) zoom on the corner

REMARKS

- This solution is generally applied on masonry walls with embedded timber posts bearing the roof structure. It is used to avoid a lack of stability of the whole structure once the base of the posts is rotten.

FIND OUT MORE

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TECHNIQUE

BAMBOOS EMBEDDED INTO EARTHEN WALLS

CONCERNED PARTS

Walls

PROBLEMS

Diagonal cracking, tensile stresses, differential settlement, shrinkage

LOCATION

Bangladesh: Khulna, Rajshahi
China: Fujian province
Colombia

CURRENT & FUTURE APPLICATION

● At risk

BRIEF DESCRIPTION

Bamboo culms or slices are embedded into massive rammed earth or cob walls. Bamboo pieces are placed horizontally on the entire length of the wall with a vertical spacing running from 10 to 60 cm. In some cases, bamboo pieces from perpendicular walls are connected to each other in the corners forming continuous bands along the entire building.

1) Bangladesh: bamboo slices embedded into a cob wall; 2) Colombia: culms from a thin and solid type of bamboo embedded into a rammed earth wall

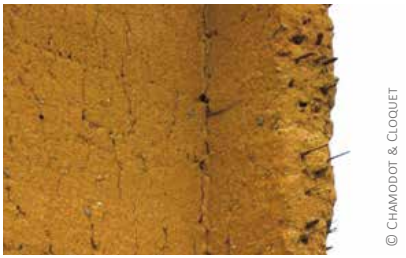
VULNERABILITY REDUCTION

The bamboos act as reinforcing bars similarly to steel bars for reinforced concrete. Thanks to bamboo high tensile strength, they improve the behaviour of the wall under horizontal seismic stresses, counterbalancing the low resistance to traction of massive earthen walls.

In addition, they contribute in considerably reducing structural cracking of the wall, horizontal deformations induced by seismic loads as well as vertical deformation caused by differential settlement of the ground.
The connexion of bamboo pieces in the corners provides additional strength and improved structural cohesion linking together perpendicular walls.
Bamboo pieces embedded into earthen walls also contribute to reducing the shrinkage of the wall during drying, avoiding significant deformations that could affect the walls bearing capacity.

REMARKS

- The number of pieces used for each layer varies according to the size, the shape (whole or sliced bamboo) and the type of bamboo, with generally a minimum of 2 pieces.



China: 3 & 4) thin bamboos embedded into the mass of the rammed earth walls of XI century tulou houses in Fujian province

FIND OUT MORE

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TECHNIQUE

SEISMIC REED ISOLATOR EMBEDDED INTO MASONRY WALLS

CONCERNED PARTS	PROBLEMS
Walls	Cracking of the masonry Horizontal movements
LOCATION	**CURRENT & FUTURE APPLICATION**
Afghanistan Uzbekistan	● Not applied anymore

BRIEF DESCRIPTION

Layers of reeds are placed between the foundations and the masonry superstructure. In some cases, mats of woven straw are used instead of reeds.

Uzbekistan: 1) walled town Itchan Kala; 2) straw woven mats integrated into the masonry wall

VULNERABILITY REDUCTION / HYPOTHESIS

The layers of reeds create a disconnection between the building and the ground. The superstructure is free to move as a whole independently from the ground and the foundations while the layers of reeds work as absorber of lateral loads.
During earthquakes, slipping may occur between the foundations and the superstructure with small movements reducing stresses inside the masonry walls and dissipating a significant amount of seismic energy. The intensity of lateral forces on the superstructure is then reduced and the effects of the earthquake on the building are limited.

REMARKS

- This system is based on the concept of "seismic base isolation" promoted by modern earthquake engineering.
- According to archaeologists, this system seems to be quite widespread on various ancient buildings in Central Asia.

FIND OUT MORE

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Afghanistan: 4) 15th century Andkhoy mosque; 5) layers of reeds

TECHNIQUE

HORIZONTAL ROLLING LOGS AS SEISMIC ISOLATORS IN THE SUPERSTRUCTURE

CONCERNED PARTS

Walls, arches

PROBLEMS

Horizontal displacements,diagonal cracking

LOCATION

Algeria: Alger, Aurès region
Syria: Damascus

CURRENT & FUTURE APPLICATION

● Not applied anymore

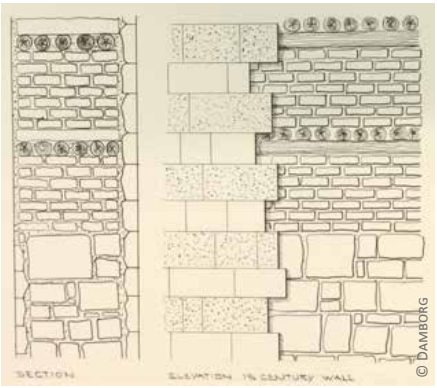
BRIEF DESCRIPTION

Round timber logs are embedded into stone or burnt brick masonry with earthen or lime mortar, according to three different methods:

- several long logs are placed horizontally covering the whole wall thickness and the entire length of the wall, with a vertical spacing of 80 to 150 cm;
- long logs are placed over small branches oriented transversally to the wall with a vertical spacing of about 40cm;
- small logs are placed on the top of the columns and at the crossing of two arcades.

VULNERABILITY REDUCTION

The horizontal logs divide the masonry wall into disconnected sections. Under lateral loads, each section moves independently from the others. Rolling of the logs and sliding of each wall section allow for seismic energy dissipation and shear forces reduction, avoiding significant deformation and diagonal cracking.
Perpendicular logs may be connected in the corners which prevents the dissociation of the walls and other vertical load-bearing elements.
Energy dissipation is increased when long logs rely on small perpendicular branches as an additional frictional interface is created and the friction damper that is created functions in both directions.
The small logs placed on the top of the columns and oriented perpendicularly to the arches provide an enhanced resistance to shear forces. They act as damper absorbing horizontal movements from the ground: during earthquakes, the column can move with the ground without affecting the upper portions of the masonry walls thanks sliding to the logs.



1) Syria: sections of a 15th century ground floor wall in Damascus

Algeria, logs in masonry walls: 2) simple layer; 3) double layer with branches perpedicular to the main logs
Algeria, small logs for arches: 4) on the top of the column; 5) at the crossing of arcades

REMARKS

- In most cases, the mortar is prepared using a very sticky type of soil. By increasing the cohesion of the masonry blocks, it enables each portion of the wall to behave and slide as a single block. The formation of cracks is thereby limited to the fuse interface created by the logs.
- The floor joists rely on beams extended from the wall by several centimetres preventing a collapse of the floor joists in case of differential displacements of the bearing structure.

FIND OUT MORE

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ABDESSEMED FOUFA, A. BENOUAR, D. 2005. «Atlas of Earthquake- Resistant Traditional Techniques in Algeria: The Case of the Casbah of Algiers. Contribution for a catalogue of earthquake-resistant traditional techniques in Northern Africa: the case of Casbah of Algiers (Algeria)». In : *European Earthquake Engineering Journal*. Vol. 2, p. 2-29.

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TECHNIQUE

HORIZONTAL LADDER-LIKE TIMBER BANDS

CONCERNED PARTS

Walls

PROBLEMS

Diagonal cracking, differential settlement, corner dissociation

LOCATION

Albania; Armenia; Bulgaria; Chile;
China: Fujian, Jiangxi, Guangdong;
Greece: Peloponnesus
India: Kashmir, Himachal Pradesh, Uttarkhand;
Iran; Macedonia; Nepal; Nicaragua;
Pakistan; Syria; Turkey;
Uzbekistan: Samarkand

CURRENT & FUTURE APPLICATION

● At risk

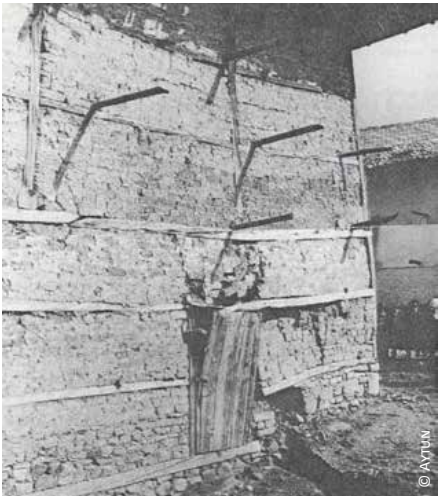
BRIEF DESCRIPTION

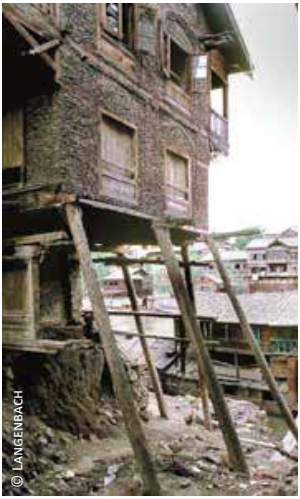
Two parallel timber beams with square or rectangular section are embedded horizontally on both sides of masonry walls and connected by small cross pieces giving the timber bands a ladder shape.
These bands are placed at regular vertical distance and are connected with different types of joints longitudinally and at the intersection between perpendicular walls.

VULNERABILITY REDUCTION

The horizontal beams tightly hold perpendicular walls together and bind the whole building at different levels, avoiding dissociation and strengthening walls towards out-of-plane lateral forces.
The timber bands work as load distribution systems within the wall as well as within the whole building. They provide a certain degree of flexibility to the walls thanks to the wood flexibility and its resistance to tensile forces.
The horizontal bands dampen vertical and horizontal stresses improving shear strength and the ability of the wall and the building to withstand differential settlement or ground failure with vertical direction.
They also provide a slip plane within the wall increasing energy dissipation thanks to the friction between the masonry units and the seismic bands. This provides ductility to the structure with an increased deformation capacity of the walls that otherwise would have a brittle behaviour.
The seismic bands contribute effectively in stopping the extension of localised failures. They prevent diagonal cracks from spreading to large wall sections.

From top left to bottom right:
1) Turkey, old town of Erzurum
2) Pakistan, Besham fort dating from 1750 in a picture taken after the 2005 earthquake: the part of the beam protruding from the perpendicular beam ensures a resistance to tension
3) Macedonia: tension resistant corner joint connecting horizontal beams from two perpendicular walls
India, Himachal Pradesh: 4) ladder shape of horizontal timber bands with cross pieces connected with tension resistant joints on the same level as the main beam; 5) hybrid system with overlapped horizontal timber bands and dry stone masonry





From top left to bottom right:
6) Turkey: a two storey earthen brick building right on a ground rupture created during the 1970 Gediz earthquake: the wall at ground floor absorbed considerable amount of deformation, leaving the upper story practically intact thanks to the horizontal timber bands provided at various levels
7) Macedonia: vertical deformation of the masonry wall during an earthquake
8) Turkey: the horizontal bands avoid a complete collapse even in case of failure at the corners, 9) and act as lintel carrying the load of the upper portions
10) India, Kashmir: the stone masonry walls are held up only by few poles supporting the horizontal timber bands bearing the joists and the upper portions of the wall

REMARKS

- The timber bands are placed at least at the floor, roof, lintel and window sill levels. Their distance varies according to the region and in relation to the local seismicity level. In some regions, the bands are placed directly one over the other forming a sort of hybrid structural system.
- Cross pieces are generally placed above the beams or, in rare cases, under them or in the same plane. Connections between cross pieces and beams are done with joints resistant to tension.
- Most common masonry types and materials are: dry stone masonry, stone masonry with earthen and/or lime mortar, sun-dried earthen bricks, burnt bricks.
- In many country, masonry with horizontal ladder-like timber bands is mainly used for the lower parts of the building while the upper stories are often built with lighter systems (such as infill timber frame).
- The horizontal timber bands embedded into masonry walls are a system found only in seismic prone areas and it is particularly widespread on the Alpine-Himalayan seismic belt.
- The effectiveness of this type of seismic bands has been officially recognized and integrated into building codes of different countries (Turkey, India, Pakistan, etc.).

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

HOFMANN, M. 2015. *Le facteur séisme dans l'architecture vernaculaire: un décryptage entre déterminants culturels, types de structures et ressources cognitives parasismiques*. PhD thesis. Lausanne: Swiss Federal Institute of Technology.

LANGENBACH, R. 2009. *Don't tear it down. Preserving the earthquake resistant vernacular architecture of Kashmir*. New Delhi: UNESCO.

SCHACHER, T. 2007. *Bhatar construction. Timber reinforced masonry. An illustrated guide for craftsmen*. Mansehra: Swiss Agency for Development and Cooperation, French Red Cross.

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TECHNIQUE

MASONRY LAYERS WITH FISHBONE PATTERNS

CONCERNED PARTS

Walls

PROBLEMS

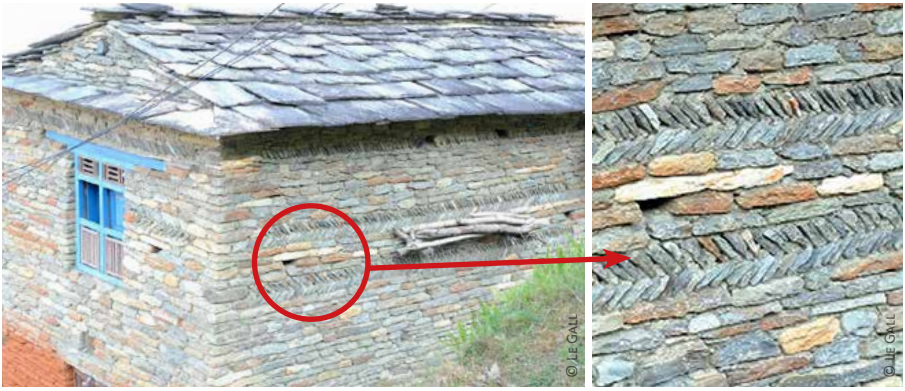
Diagonal cracking of the masonry

LOCATION

Algeria: Alger
Italy: Alps
Nepal: Myagdi district
Turkey: Karabük Province

CURRENT & FUTURE APPLICATION

● At risk



Nepal, after the 2015 M 7.8 Gorkha earthquake: 1) diagonal courses in stone masonry walls with corner stones; 2) opposite directions of layers

BRIEF DESCRIPTION

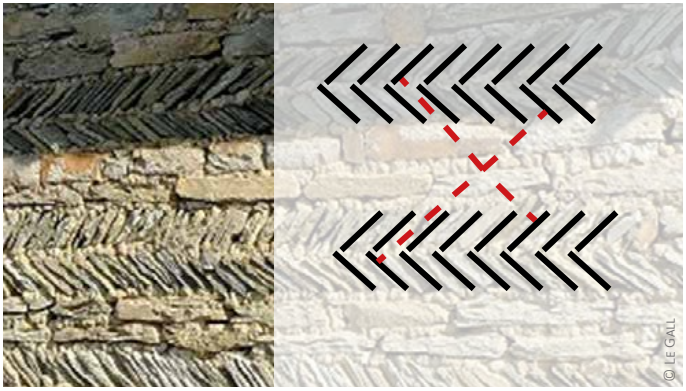
At regular spacing, two layers of stone masonry with mud mortar are arranged following a fishbone pattern: small flat stones are diagonally placed with a 45° inclination in one direction for the first layer and in the opposite direction for the second one.

VULNERABILITY REDUCTION / HYPOTHESIS

During earthquakes, diagonal cracks that may occur in the masonry are diverted by the diagonal course placed with opposite inclination, reducing the risk of a major failure of the wall. In addition, with this arrangement friction surface within the wall is increased, enhancing dissipation of the seismic energy.
The fishbone arrangement strengthens the structure of the walls distributing forces that could concentrate on the vertical joint lines and compensating differential soil settlement and irregularities due to improper masonry work.

REMARKS

- Carved stones are used for the corners of the building in order to improve its stability and ensure a proper bonding between perpendicular walls.
- Stones in the lower layer and the upper one of the following diagonal course usually have opposite directions.



3) Interruption of diagonal cracking by 45° stones (hypothesis)

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

HOFMANN, M. 2015. *Le facteur séisme dans l'architecture vernaculaire: un décryptage entre déterminants culturels, types de structures et ressources cognitives parasismiques*. PhD thesis. Lausanne: Swiss Federal Institute of Technology.

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TECHNIQUE

CONTINUOUS FLAT STONE COURSES

CONCERNED PARTS	PROBLEMS
Walls	Masonry delamination, diagonal cracking
LOCATION	**CURRENT & FUTURE APPLICATION**
Nepal: Myagdi district	● At risk

BRIEF DESCRIPTION

In stone masonry walls, large slabs of flat stones are placed end to end creating one or more continuous courses running along the entire length of the wall.

VULNERABILITY REDUCTION

The long stones cover the whole thickness of the wall, providing stability and horizontal stiffness to the masonry. They lock together the two sides of the wall preventing them from working separately and thereby avoiding masonry delamination and failure of the wall. Moreover, they prevent the propagation of diagonal cracks to the entire wall.

Nepal: flat stone course in a building that withstood the 2015 M 7.8 Gorkha earthquake
1) general view & 2) detail

FIND OUT MORE

FERREIRA MENDES, M. HOSTA, J. LE GALL, O. 2015. *Technical guide for master trainers: Earthquake resistant buildings using local materials in Dolakha, Ramechhap and Sindhuli - Nepal*. Grenoble: CRAterre, Nepal Red Cross Society, Swiss Red Cross.

TECHNIQUE

BAKED BRICKS IN SUN DRIED BRICKS VAULTS

CONCERNED PARTS

Vaults

PROBLEMS

Vault collapse

LOCATION

Iran: Yazd

CURRENT & FUTURE APPLICATION

● Not applied anymore

BRIEF DESCRIPTION

Rows of baked bricks are inserted into sun dried bricks vaults, approximately every 50 cm.

VULNERABILITY REDUCTION / HYPOTHESIS

This technique improves the global stability of vaults. It probably relies on the lower adhesion between baked bricks and clay mortar than between sun dried bricks and clay mortar. In case of a quake, the cracks first appear at those weak interfaces. It thus prevents diagonal cracks. The sectional cracks that form at those fuse interfaces divide the vault in arches that keep on being stable. The formation of cracks and the local shifts that occur at those interfaces allow for seismic energy dissipation.

REMARKS

- Horizontal rows of baked bricks are sometimes inserted in earthen walls (for example in Andalusia, Spain). It probably also functions as a fuse interface and can be considered as a substitute to seismic timber bands in areas where wood is a scarce resource.

FIND OUT MORE

CRÉTÉ, E. 2016. *L'architecture en terre crue face aux catastrophes : oubli des stratégies traditionnelles et enjeux en période de reconstruction*. Mémoire du DSA Terre. Grenoble: École Nationale Supérieure d'Architecture de Grenoble.

Iran: adobe vaults in a traditional house in Yazd, 1) the cracks and 2) partial collapse formed at the interfaces between baked bricks and sun dried bricks

TECHNIQUE

MASONRY LAYOUT
CREATING A DISSIPATIVE BAS-RELIEF

CONCERNED PARTS

Walls

PROBLEMS

Uncontrolled cracks

LOCATION

Iran: Yazd, Shiraz
Afghanistan: Shahr e Zohak, Jam minaret
Uzbekistan: Bukhara

CURRENT & FUTURE APPLICATION

● Not applied anymore

BRIEF DESCRIPTION

Specific patterns are often used in masonry decorative sheathings of major buildings (in particular in case of a military function). Offsets between sun dried bricks create a bas-relief on the façade.

VULNERABILITY REDUCTION / HYPOTHESIS

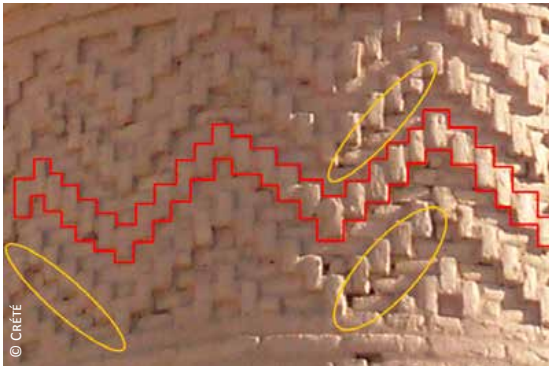
The offsets between sun dried bricks create blocks that have a greater contact surface and better cohesions than with the surrounding blocks. The design of those blocks is such that they are interlocked. In case of extraordinary loads, local shifts between blocks are probable, but global ones are not. Local shifts are benefic as they help dissipating energy. This feature can be understood as a variation of cyclopean stonework.
Cracks (circled in yellow in pic.2) are more likely to appear at the interface between two blocks that are made more cohesive thanks to greater contact surface between sun dried bricks (one example of these blocks outlined in red in pic.2).

REMARKS

- This technique resulted in an architectural vocabulary that is wide-spread in Central Asia.
- This technique is typical of medieval buildings (9th–13th centuries). It was then briefly reintroduced by Zand dynasty in Iran (18th century).
- Military buildings are built to resist important lateral loads and vibrations. Their resistance often relies on the same techniques as the one used for seismic reasons.

FIND OUT MORE

CRÉTÉ, E. 2016. *L'architecture en terre crue face aux catastrophes : oubli des stratégies traditionnelles et enjeux en période de reconstruction*. Mémoire du DSA Terre. Grenoble: École Nationale Supérieure d'Architecture de Grenoble



Iran:
1) Dolat Abad Garden fortifications in Yazd
2) Kharanaq shaking minaret

TECHNIQUE

INTERLOCKING MASONRY BLOCKS

CONCERNED PARTS	PROBLEMS
Walls	Masonry dissociation, diagonal cracking
LOCATION	**CURRENT & FUTURE APPLICATION**
Cambodia, Egypt, Greece, Peru	● Not applied anymore

BRIEF DESCRIPTION

Notches are carved in the corners and on the sides of each unit of dry stone masonry. The different blocks perfectly fit within the wall and are interlocked to the nearby units.

VULNERABILITY REDUCTION

The notches and the three-dimensional carving of each unit create a non-linear joint pattern increasing the structural cohesion of the wall, preventing diagonal cracking and limiting vertical and out-of plane displacements. Moreover, small movements can take place between the stones. This contributes to the dissipation of seismic energy by friction.

REMARKS

- This type of connection between masonry units requires high skills and very precise work. It is generally found in very ancient buildings and it is not applied anymore.
- In some cases, interlocking is obtained using a connection piece, generally from a flexible material (like wood or lead) inserted into grooves carved in the masonry blocks and working as clips linking them together.

1) Cambodia, Beng Mealea temple; 2) Peru, wall in Cusco; 3) Egypt: grooves to install the pieces to connect blocks of the same row

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

TECHNIQUE

HALF-SOLID WALL

CONCERNED PARTS	PROBLEMS
Walls	Water erosion, soil moisture
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Chittagong, Mymensingh, Sylhet	● Commonly known and applied

BRIEF DESCRIPTION

A half wall built with long lasting materials is used for the lower part of the structure.

VULNERABILITY REDUCTION

The lower portion of the wall is more resistant to water erosion. Total cost is reduced as the upper portions can be built with cheaper materials.

Bangladesh: 1) earthen wall with reed fences; 2) burnt bricks wall with bamboo fences; 3) cement blocks wall with iron sheet fences

REMARKS

- Half earthen walls are sensitive to water erosion and moisture but they can be easily maintained and are cheap to repair. They also contribute in improving indoor comfort.
- This solution is also safe in case of floods and earthquakes as heavy materials are used only in the lower portions of the walls, reducing the risk of injury in case of partial collapse.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

TECHNIQUE

LIGHTENED AND FLEXIBLE UPPER PORTIONS OF WALLS

CONCERNED PARTS	PROBLEMS
Walls	Collapse of the walls
LOCATION	**CURRENT & FUTURE APPLICATION**
Haiti: South-East department Bangladesh: Sylhet	● Commonly known and applied

BRIEF DESCRIPTION

The upper parts of the walls have a decreased thickness and/or are built with materials lighter and more flexible than those used for the lower parts.

VULNERABILITY REDUCTION

Thanks to these greater lightness and flexibility, the upper portion is able to follow the movements produced by the earthquake without cracking.
In case of partial collapse of the wall, the risk of serious injuries to the occupants is considerably limited thanks to the reduced weight of the materials used.

Haiti: 1) change in the materials: lower part with masonry walls and upper part with woven coconut sticks; 2) decreasing the thickness of masonry walls

REMARKS

- In the lower portions, long-lasting materials (stone or cement block masonry, earthen massive walls) are generally used to ensure a better protection from moisture or a better inside comfort. Lighter materials (such as bamboo or reed woven mats) are generally cheaper but more vulnerable to humidity. This solution helps improving the durability of the construction while keeping limited cost.
- This solution is often used in association with an independent frame structure bearing the roof.
- Repairing work can be easily done on the lower portion of the wall as damage is localized and the upper parts of the structure generally remain unaffected.
- A variation of this technique is commonly found, for example in Portugal, Turkye, Syria, Egypt and Greece: first floor walls are timber-framed which makes them lighter and more flexible than the massive ground floor masonry walls (*cf p. 6*).

FIND OUT MORE

CAIMI, A. GUILLAUD, H. MOLES, O. et al., 2013. « Traditional and scientific knowledge for a sustainable vulnerability reduction of rural housing in Haiti ». In: *Structures and Architecture: Concepts, Applications and Challenges*. Guimarães: CRC Press / Taylor & Francis, 2013. p. 1807-1815.

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

Bangladesh: 3) half earthen wall and upper part with jute stick panels; 4) wall damaged during floods and temporarily repaired with lighter materials

TECHNIQUE

CROSS BRACING

CONCERNED PARTS	PROBLEMS
Structural frame	Bending and/or collapse of the structure
LOCATION	**CURRENT & FUTURE APPLICATION**
Haiti: rural and urban areas	● At risk

BRIEF DESCRIPTION

Diagonal crosses are built with timber planks between the posts of the main structure. The spaces between the structure and the crosses are filled with stone masonry as walling or kept empty as the enclosure system of the veranda.

Haiti, rural areas: 1) cross bracing stabilizing the structural frame even in case of failure of the lower masonry wall during the 2010 earthquake; 2) cross bracing of the roof bearing structure

VULNERABILITY REDUCTION

The crossed timber planks work as bracing, improving the behaviour and the resistance of the structure under horizontal loads, such as those generated by earthquakes and strong winds.

Even if the infill is damaged or the lower portions of the masonry walls fail, the structure keeps a relative consistency avoiding a complete collapse.

REMARKS

- After the 2010 earthquake, several cases were observed of buildings still standing even if showing heavy damage of the lower masonry stories.
- Nowadays, the use of cross bracing is barely found and is observed mainly in old buildings. A loss of knowledge about its function and an increasing shortage of wood are probably the causes of this limited diffusion.

FIND OUT MORE

AUDEFROY, J. F., 2011. «Haiti: post-earthquake lessons learned from traditional construction». In: *Environment & Urbanization*. October 2011. Vol. 23, n°2, p.447-462.

CAIMI, A. GUILLAUD, H. MOLES, O. et al., 2013. « Traditional and scientific knowledge for a sustainable vulnerability reduction of rural housing in Haiti ». In: *Structures and Architecture: Concepts, Applications and Challenges*. Guimarães: CRC Press / Taylor & Francis, 2013. p. 1807-1815.

LANGENBACH, R. KELLEY, S. SPARKS, P. et al., 2010. *Preserving Haiti's Gingerbread Houses. 2010 Earthquake Mission Report*. New York: World Monuments Fund, ICOMOS.

Haiti, urban areas: 3) decoration at the top and bottom of the posts working as cross bracing; 4) the bracing helps in keeping the upper storey in place in a gingerbread house after 2010 earthquake

TECHNIQUE

Y-BRACING

CONCERNED PARTS

Structural frame

PROBLEMS

Bending and/or collapse of the structure

LOCATION

Peru: Lima; Turkey: Tokat province

CURRENT & FUTURE APPLICATION

● At risk

BRIEF DESCRIPTION

Bracing with Y-shape or inverted Y-shape are placed within a timber structural frame.

VULNERABILITY REDUCTION

Even if less effective than cross bracing, Y-shape bracing provides cohesion and improved stability to the structure avoiding its bending and collapse.

REMARKS

- This type of bracing is often used on main façades, especially on the corners and near windows, as X-shape bracing is more difficult to combine with openings.
- It has often been used in regions where intensity of past earthquakes was moderate.

FIND OUT MORE

HOFMANN, M. 2015. *Le facteur séisme dans l'architecture vernaculaire: un décryptage entre déterminants culturels, types de structures et ressources cognitives parasismiques*. PhD thesis. Lausanne: Swiss Federal Institute of Technology.

1) Turkey: inverted Y-bracing on the main façade between windows; 2 & 3) Perou, Lima: Y-bracing on an historical building

TECHNIQUE

CORNER BRACING

CONCERNED PARTS

Structural frame

PROBLEMS

Bending and/or collapse of the structure

LOCATION

Bangladesh: Sylhet
Haiti: South-East department

CURRENT & FUTURE APPLICATION

● At risk

BRIEF DESCRIPTION

Short pieces of wood are diagonally placed at the corners of the structural frame.

VULNERABILITY REDUCTION

The wooden pieces work as bracing avoiding the structure to bend under lateral loads due to earthquakes or strong winds.

REMARKS

- Short bracing are cheaper than the long ones and less problematic for placing doors and windows.
- Generally, the corner bracing are fixed with nails, in some cases they are provided with mortise to ensure a better fitting and connexion with the structural frame.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CAIMI, A. GUILLAUD, H. MOLES, O. et al., 2013. « Traditional and scientific knowledge for a sustainable vulnerability reduction of rural housing in Haiti ». In: *Structures and Architecture: Concepts, Applications and Challenges*. Guimarães: CRC Press / Taylor & Francis, 2013. p. 1807-1815.

1) Bangladesh: corner bracing placed on the top of the ring beams; 2) Philippines: corner bracing in a house rebuilt after 2013 typhoon Hayan

TECHNIQUE

FRICTION DAMPER TIMBER CAPITAL

CONCERNED PARTS	PROBLEMS
Structural frame	Failure of load-bearing beams
LOCATION	**CURRENT & FUTURE APPLICATION**
Nepal; Pakistan	● At risk

BRIEF DESCRIPTION

The beam is set on a stack of small timber planks forming a capital with an inverted pyramid shape.

VULNERABILITY REDUCTION

The posts, the small planks of the capital and the beam can move independently during earthquakes.
The superposition of several planks provides a greater number of interfaces where friction takes place under horizontal movements, increasing the dissipation of the seismic energy and thus reducing the impact of the earthquake forces on the building.

Pakistan: 1) capital; 2) capital in an existing house

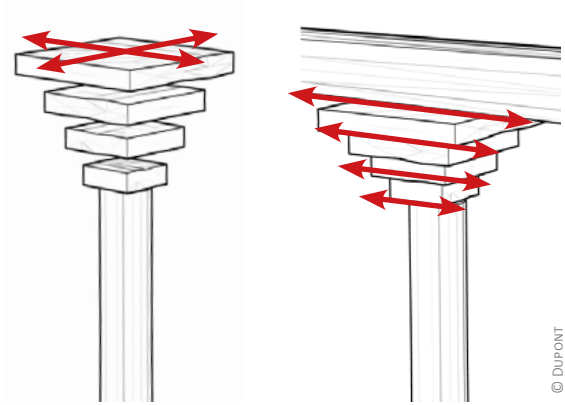
REMARKS

- The large capital reduces the risk that the beam falls from the post.
- To ensure the effectiveness of this device, flexible connections (such as nails or metal straps) are preferred to allow for slight differential movements of the structure parts.
- Traditional wooden *muqarna* capitals (Iran, Iraq) were made of several pieces of wood nailed together and may be a variation of this technique.

FIND OUT MORE

DUPONT, M. 2006. *Technical guide for master trainers: Earthquake resistant buildings using local materials in Kafal Ghar (Kashmir, Pakistan)*. Grenoble : CRAterre.

FERREIRA MENDES, M. 2015. *Support for the Swiss Red Cross for reconstruction in Nepal*. Mission report. Villefontatine: CRAterre.



Capital behaviour: 3) bidirectional movements; 4) differential displacements of the layer of the capital under horizontal forces

TECHNIQUE

MOVING LOAD BEARING BEAMS

CONCERNED PARTS	PROBLEMS
Floor beams	Punching of the walls
LOCATION	**CURRENT & FUTURE APPLICATION**
Bangladesh: Rajshahi	● At risk

BRIEF DESCRIPTION

A hole is left into the masonry wall in order to let the load bearing beam pass through without any locked joint.

VULNERABILITY REDUCTION

The holes are a little bit bigger than the size of the beams. During earthquakes, the beams are free to move horizontally and independently from the walls without affecting the main masonry structure. It thus prevents cracks and failures due to punching.

Bangladesh: 1) upper floor beams free to move; 2) behaviour under lateral forces

REMARKS

- In some cases, the beams are extended protruding from the other side of the wall, allowing bi-directional movements and reducing the risk of collapse due to lack of structural support during earthquakes.

FIND OUT MORE

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

TECHNIQUE

CONFINED GABLE MASONRY WALL

CONCERNED PARTS	PROBLEMS
Walls	Wall collapse
LOCATION	**CURRENT & FUTURE APPLICATION**
Nepal: Myagdi district	● At risk

BRIEF DESCRIPTION

Gable walls built with stone masonry (with and without mud mortar) are confined using twisted steel cables or timber studs connecting the rafters to one or several timber elements embedded longitudinally in the wall thickness.

VULNERABILITY REDUCTION

In case of an earthquake, the cables and the studs prevent the gable wall from tilting. It thereby limits damage and reduces the risk of injuries for the inhabitants.

Nepal, light roof with confined gable walls using 1) steel cables and 2) timber studs

REMARKS

- This device is used mainly for light roof buildings as the load of the roof on the masonry walls is not sufficient to compress and to stabilize it in case of strong shaking.

FIND OUT MORE

FERREIRA MENDES, M. HOSTA, J. LE GALL, O. 2015. *Technical guide for master trainers: Earthquake resistant buildings using local materials in Dolakha, Ramechhap and Sindhuli - Nepal*. Grenoble: CRAterre, Nepal Red Cross Society, Swiss Red Cross.

TECHNIQUE

FIXING KEYS ON BEAMS

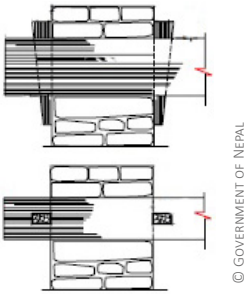
CONCERNED PARTS	PROBLEMS
Walls, beams	Beam displacements and failure
LOCATION	**CURRENT & FUTURE APPLICATION**
Nepal: Myagdi district	● Commonly known and applied

BRIEF DESCRIPTION

In stone masonry walls, timber horizontal structural elements (such as beams, lintels, joists, wall plates) are fixed with a timber key inserted into timber pieces on both external and internal sides of the walls. The key passes through one or more timber elements that, in some cases, are the structural elements themselves extended beyond the walls.

VULNERABILITY REDUCTION

The fixing key keeps in place the structural elements embedded or placed against the masonry walls. It provides a flexible and non rigid connection that let the horizontal elements free to move during earthquakes while ensuring a structural cohesion under in-plane and out-of-plane movements. By doing so, it also increases the dissipation of seismic energy by friction without generating major failures.



Nepal: 1) simple key and 2) double key in masonry buildings after the 2015 M 7.8 Gorkha earthquake; Detail from the Nepal National Building Code: 3) section and 4) plan

REMARKS

- This device is recognized as en effective system and it is recommended in the Nepal Building Code for earthquake resistant construction.

FIND OUT MORE

GOVERNMENT OF NEPAL. 1994. *Nepal National Building Code. Guidelines for earthquake resistant building construction: low strength masonry*. Kathmandu: Ministry of Physical Planning and Works.

TECHNIQUE

TIMBER PEGS ON STONE MASONRY

CONCERNED PARTS	PROBLEMS
Walls, beams	Displacements of structural elements
LOCATION	**CURRENT & FUTURE APPLICATION**
Nepal: Myagdi district	● At risk

BRIEF DESCRIPTION

A timber peg is inserted into a hole drilled in the cantilever portion of a flat stone embedded into a masonry wall and supporting a timber element (lintel, seismic band, wall plate).

VULNERABILITY REDUCTION

The timber peg keeps the timber element in place, avoiding tilting outwards during earthquakes. It provides a flexible and non rigid connection letting the timber element free to move under seismic loads while avoiding its loosening. It thereby increases energy dissipation by enhanced friction between the structural elements.

REMARKS

- This connection is not much widespread due to the time and work required to drill the hole. A similar system is generally preferred using a timber element instead of the flat stone perpendicularly embedded into the wall thickness.

FIND OUT MORE

MOLES, O. 2016. *Seismic bands. Lessons from local building cultures*. Presented at IFRC-SRU Conference "Innovative Humanitarian Shelter: Assessing existing solutions & proposing new ideas". Berlin, 3- 4 May 2016.

Nepal, after the 2015 M 7.8 Gorkha earthquake: 1 & 2) timber pegs blocking a timber beam

TECHNIQUE

STRUCTURAL JOINTS SECURED WITH REMOVABLE WEDGES

CONCERNED PARTS

Structural frame, joints

PROBLEMS

Frame collapse,
breaking of structural elements

LOCATION

Indonesia: Aceh, Nias Islands, Sumatera Utara

CURRENT & FUTURE APPLICATION

● At risk

BRIEF DESCRIPTION

The main structural elements are connected using mortise and tenon joints blocked by a wooden wedge.

Indonesia: 1) joints with wedges for the floor structure of local stilt houses in Aceh province; 2) behaviour in case of strong earthquake

VULNERABILITY REDUCTION

During earthquakes, the mortise and tenon joints allow the structural elements to move, dissipating the seismic energy. If the shaking is too strong, the wedge slips out providing additional flexibility to the structure and avoiding the structural elements to break. The wedges work as dampers of the movements imparted into structures by earthquake ground motions, and as safety valves reducing the risk of severe damage to the main structure.

REMARKS

- Once the wedges slip out, the structural elements are kept together by the loosened joint, avoiding a complete collapse of the structure.
- The structure can be quickly set upright as the wedges can be easily insert again in the joints with some hammer blows.

FIND OUT MORE

CAIMI, A. & HOFMANN, M. 2010. *Aléas naturels, reconstruction et pratiques vernaculaires*. Post-Master DSA thesis. Grenoble: CRAterre-ENSAG.

Indonesia: 3) double wedge for the post-floor beam connection

TECHNIQUE

PEGGED TENON AND MORTISE JOINTS

CONCERNED PARTS	PROBLEMS
Structural frame, joints	Structural dissociation, breaking of structural elements

LOCATION	CURRENT & FUTURE APPLICATION
Haiti: South-East and North-West departments	● At risk

BRIEF DESCRIPTION

Structural members of the timber frame are connected together using tenon and mortise joints fixed with long wooden pegs.

VULNERABILITY REDUCTION

The tenon and mortise joints provide flexible connections enabling the structure to move under lateral loads and three-dimensional forces induced by earthquakes or cyclonic winds. The wooden peg holds together the timber elements; its length allows for important movements and sliding while providing a sufficient safety margin to avoid dissociation of the connected elements.

The whole frame can swing and deform without the risk of a sudden collapse due to the break of structural elements caused by stiff points at the connections. In case very important deformations occur, inhabitants have time to leave the building and move in a safer place.

Haiti: 1) beam-post connection with long peg; 2) double pegged joint connecting the post to the beam and the roof structure to the beam; 3) pegged joint for connecting two parts of the top beam

REMARKS

- This type of joints is used for connecting posts to beams, trusses to beams and in some cases also the different parts of the trusses.
- Even if the structural frame deforms and bends, its members are still firmly connected together. The structure can then be straightened up again and repaired starting from the existing frame.
- This type of joint is more and more replaced by a simple nail connection, easier to produce but more likely to induce structural elements dismantling and more sensitive to the quality of execution (e.g. sufficient number of nails).

FIND OUT MORE

CAIMI, A. GUILLAUD, H. MOLES, O. et al., 2013. « Traditional and scientific knowledge for a sustainable vulnerability reduction of rural housing in Haiti ». In: *Structures and Architecture: Concepts, Applications and Challenges*. Guimarães: CRC Press / Taylor & Francis, 2013. p. 1807-1815.

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

Haiti: 4) pegged tenon and mortise joints are used for each connection between structural elements, including for the roof structure; 5) during 2010 earthquake the building was damaged but the main structure was able to withstand

PRACTICE

FLEXIBLE VEGETABLE TIES

CONCERNED PARTS

Structural frame, connections

PROBLEMS

Breaking of structural elements

LOCATION

Philippines: Aklan province
Vanuatu

CURRENT & FUTURE APPLICATION

● Commonly known and applied

BRIEF DESCRIPTION

Structural elements are tied together without nails using vegetable materials such as creepers, rattan or coconut fibre ropes.

1) Philippines: rattan ties for connecting posts, ring beam and roof structure
Vanuatu: 2) ties with creepers; 3) movements of the structural elements under wind loads

VULNERABILITY REDUCTION

The vegetable ties provide non rigid connections that let the structural elements free to slightly move while ensuring structural solidarity.
In case of heavy solicitations, the flexible connection gets loosen and the structural elements may be pulled out without breaking, so that they can be reused for the reconstruction of the structure.

REMARKS

- Vegetable ties are often replaced with nails requiring a lower skill level but providing a rigid connection that can weaken the structure and cause cracking in the structural elements, especially bamboo.

FIND OUT MORE

CAIMI, A. 2015. *Shelter and livelihood improvement project for the indigenous communities of Aklan, Philippines. Recovery after typhoon Yolanda*. Mission report. Kalibo: CRAterre, DSAC-Kalibo, Secours Catholique-Caritas France, Caritas International Belgium.

CRAterre, 2016. *Vanuatu. Forces, faiblesses et améliorations de l'habitat traditionnel*. Pedagogical guide. Villefontaine: CRAterre, Vanuatu Red Cross Society, French Red Cross.

Uganda:
a thatched house

ROOFING

FLOATING ROOF 101
Floods Practice Bangladesh

ROOF SHORING FOR SHELTERING DURING RECONSTRUCTION 102
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Durability Practice Uganda

PRACTICE

FLOATING ROOF

CONCERNED PARTS	PROBLEMS
Roof structure and covering	Sinking of the roof
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh	● Commonly known and applied

BRIEF DESCRIPTION

Empty jerrycans are fastened under the roof structure.

VULNERABILITY REDUCTION

During high floods, the jerrycans work as floats avoiding a complete sinking of the roof. Damage to the roof is significantly reduced as the whole roof will be kept above the water level.

Bangladesh: 1) empty jerrycans suspended to the roof structure; 2) a floating roof during a flood

REMARKS

- A fast recover of the roof is possible as its whole structure is preserved and covering material can be partially or totally reused.
- The saved roof can be used as provisional shelter.

FIND OUT MORE

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh.* Villefontaine: CRAterre.

PRACTICE

ROOF SHORING FOR SHELTERING DURING RECONSTRUCTION

CONCERNED PARTS	PROBLEMS
Structure, covering	Emergency sheltering
LOCATION	**PRESENT & FUTURE APPLICATION**
Haiti: South-East department	● Commonly known and applied

BRIEF DESCRIPTION

Bended posts are straightened up and, if needed, stabilized with struts. The space under the roof is used as a shelter during the time required for repairing or rebuilding the damaged house. The construction works are carried out while people are living on-site.

VULNERABILITY REDUCTION

This practice offers a good solution to the problem of quickly rehousing affected people after a disaster. In the immediate aftermath of the crisis, it provides them with a place to stay within their own community in a familiar environment as well as a shelter while waiting for the end of construction works. A transitional shelter is no longer needed and investments can go directly into the recovery process.

Haiti: 1) inside shelter using existing structure

Haiti: 2) reconstruction around the existing house

REMARKS

- Straightening up the posts bearing the roof can easily be done by the people themselves.
- Parts of the existing house (partitions, openings, etc.) and debris can be reused to fence the space under the roof at minor cost.
- According to the level of damage and the owner capacity, the house can be rebuilt around the existing damaged structure before its demolition.

FIND OUT MORE

MOLES, O. 2011. *Reconstruction post-séisme 2010. Projet de reconstruction de 100 maisons et 20 citernes à Cap Rouge*. Port-au-Prince: CRAterre, Vedek, Secours Catholique-Caritas France.

TECHNIQUE

DIAGONAL ROOF BRACE

CONCERNED PARTS	PROBLEMS
Roof structure	Bending of the roof structure
LOCATION	**PRESENT & FUTURE APPLICATION**
Haiti: South-East department	● Not applied anymore

BRIEF DESCRIPTION

Short wooden pieces are diagonally placed between the king posts of the trusses and the ridge beam.

VULNERABILITY REDUCTION

The diagonal pieces work as bracing for the roof structure preventing bending and overthrow of the trusses under strong winds.

REMARKS

- This solution is very effective when applied together with diagonal bracing in the roof planes.
- On four-sided roofs, it complements the bracing provided by the corner rafters improving the overall resistance of the roof structure.
- Short braces are cheaper than the longer ones and the space under the roof can be used as an attic for storing goods and people to stay.

Haiti: diagonal bracing connecting the king post to the ridge beam

FIND OUT MORE

CAIMI, A. GUILLAUD, H. MOLES, O. et al., 2013. « Traditional and scientific knowledge for a sustainable vulnerability reduction of rural housing in Haiti ». In: *Structures and Architecture: Concepts, Applications and Challenges*. Guimarães: CRC Press / Taylor & Francis, 2013. p. 1807-1815.

TECHNIQUE

DIAGONAL BRACING IN THE ROOF PLANE

CONCERNED PARTS	PROBLEMS
Roof structure	Roof twisting
LOCATION	**PRESENT & FUTURE APPLICATION**
Haiti: South-East department	● At risk

BRIEF DESCRIPTION

On pitched roofs, a diagonal timber element is placed between the rafter and the ring-beam on top of the walls, at both bottom corners of each roof panel.

1) Bangladesh; 2) Haiti: diagonal bracing connecting the roof truss and the ring beam

VULNERABILITY REDUCTION

The diagonal element braces the roof structure, improving its resistance to twisting during cyclones and strong winds.

REMARKS

- This solution is very effective when applied together with cross bracing of the trusses or diagonal bracing placed between the king post and the ridge beam.
- It is used mainly for iron sheet roofing which are more vulnerable to twisting than other types of roof.

FIND OUT MORE

MOLES, O. 2010. *Reconstruction post-séisme. Mise en place de la phase pilote du projet de reconstruction de 100 maisons à Cap Rouge avec VEDEK et PAPDA*. Mission report. Port-au-Prince: CRAterre, Secours Catholique-Caritas France.

TECHNIQUE

WALL PLATE ANCHORING TO THE WALLS

CONCERNED PARTS	PROBLEMS
Roof structure	Roof structure instability
LOCATION	**PRESENT & FUTURE APPLICATION**
India: Maharashtra	● At risk

BRIEF DESCRIPTION

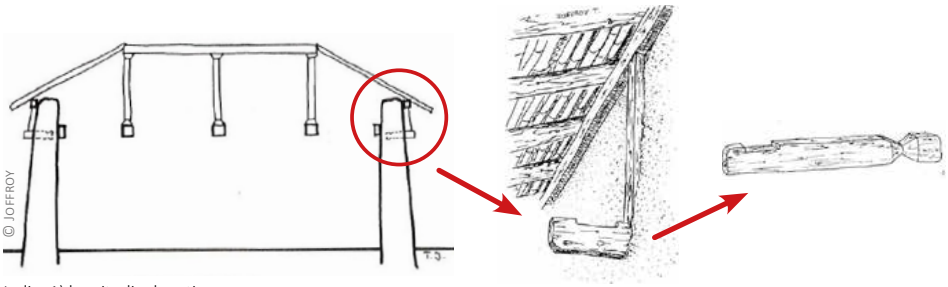
Wall plates are placed on the outside of the walls all around the building. They are supported every 1.5m by two wooden pieces: a vertical one embedded into the earthen walls and a horizontal one inserted perpendicularly into the wall. The rafters are fixed to the wall plates.

VULNERABILITY REDUCTION

This system anchors the wall plates to the roof preventing blown off. The portion of the earthen wall above the anchors provides a mass ensuring the stabilization of the wooden pieces.

In addition, the overall system brings stiffness to the roof counterbalancing the lack of bracing and improving its stability in case of strong winds. It also works like a belt keeping the walls together.

The wooden piece inserted perpendicularly into the wall has a special carving to improve its connection to the wall and to avoid pullout.



India: 1) longitudinal section;
2) wooden pieces inserted vertically and transversally into the wall;
3) detail of the horizontal piece with special carvings, on the left, for anchoring into the wall and, on the right, for installing the extension wall plate

REMARKS

- The wooden piece inserted into the wall is often also used as a support for a roof extension. To this purpose, the portion extending from the wall is carved for installing a wall plate for the roof of the extension.
- This system is generally used for massive cob walls but it is also found on 2-storey burnt brick houses.

FIND OUT MORE

JOFFROY, T. 1984. *Arcs, domes et construction en terre. Expériences de terrain*. Diploma thesis. Grenoble: École d'Architecture de Grenoble.

TECHNIQUE

LIGHT ROOF ANCHORAGE

CONCERNED PARTS	PROBLEMS
Roof structure	Roof blowing off
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Khulna, Mymensingh, Sylhet	● Commonly known and applied

BRIEF DESCRIPTION

In buildings with massive earthen walls, top plates are tied on both sides with ropes to horizontal bamboo pieces or bricks embedded through the walls.

VULNERABILITY REDUCTION

Tying the roof frame to the walls prevents the roof from being blown off or distorted, especially when iron sheets are used as covering.

Bangladesh: 1 & 2) anchoring with bamboo pieces embedded into the earthen walls

REMARKS

- This anchoring system is a minimalist but very effective solution, not requiring particular skills or an important financial effort to be implemented.
- The top of the wall is to be protected with a harder material to avoid the erosion due to the friction of the ropes.

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

Bangladesh: 3) anchoring of perpendicular top plates at the building corners; 4) anchoring to bricks

PRACTICE

ROOF ANCHORAGE TO THE GROUND

CONCERNED PARTS	PROBLEMS
Roof structure	Roof blowing off
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Khulna, Rajshahi Benin	● Commonly known and applied

BRIEF DESCRIPTION

Roof trusses and beams are anchored to the ground using ropes fastened to wood stakes or existing roots.

VULNERABILITY REDUCTION

Fastening the roof structure provides an additional connexion thus preventing the roof from being entirely blown off under wind pressure. The roof structure can slightly move but it is kept in place avoiding wrenching and severe damage.

Bangladesh: anchoring using 1) ropes and wood stakes, 2) existing roots and 3) used tyres

REMARKS

- This system can be applied with different covering materials and to any roof shape, in a permanent manner or temporarily just before the arrival of a storm.
- In some cases, used tyres are fixed to the ground to ensure longer lasting of the anchorage.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2013. *Boîte image: bonnes pratiques locales. Réduction de la vulnérabilité aux inondations des populations (et de leur cadre bâti) d'Afrique de l'Ouest et Centrale, Benin.* Villefontaine: IFRC, CRAterre.

Benin: 4) a rope tied to the roof structure provides a potential anchoring system
5) during the windy season, ropes are anchored to big stones at the corners of the building

TECHNIQUE

ROOF ANCHORAGE TO TREES

CONCERNED PARTS

Roof structure

PROBLEMS

Roof wrenching

LOCATION

Bangladesh: Barisal, Khulna
Philippines: Aklan province

PRESENT & FUTURE APPLICATION

● Commonly known and applied

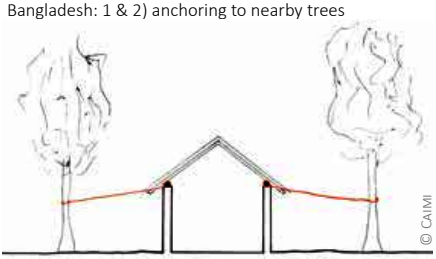
BRIEF DESCRIPTION

Roof trusses and beams are fastened to nearby trees using ropes.

VULNERABILITY REDUCTION

Fastening of the roof structure provides an additional connexion preventing the roof from being entirely blown off under wind pressure.

Bangladesh: 1 & 2) anchoring to nearby trees



REMARKS

- This system is generally applied temporarily just before the arrival of a storm.
- Under strong winds, the roof may move but a complete lifting up is avoided.

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

PRACTICE

ROOF COVERING STABILIZATION WITH STAKES

CONCERNED PARTS	PROBLEMS
Roof covering	Cover wrenching
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Sylhet	● Commonly known and applied

BRIEF DESCRIPTION

On both side of a 2-slope iron sheet roof, bamboos are placed above the roof covering and tied to wooden or bamboo stakes driven into the ground.

VULNERABILITY REDUCTION

Bamboos reduce risk of roof wrenching and prevent tearing off of the lightweight roof covering.

Bangladesh:
1&2) anchoring of the roof covering to stakes driven into the ground

REMARKS

- This cheap solution contributes to improving the resistance of 2-slope lightweight roofs otherwise very vulnerable to wind, especially in the portions near the gables.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

PRACTICE

OVERALL ROOF COVERING STABILIZATION

CONCERNED PARTS	PROBLEMS
Roof covering	Cover wrenching

LOCATION	PRESENT & FUTURE APPLICATION
Bangladesh: Barisal, Chittagong, Khulna, Sylhet South Korea: Jeju island	● Commonly known and applied

BRIEF DESCRIPTION

A device is placed on the roof to prevent its damaging. For example:
A fishing net is placed over tiled roofs and tied to the rafters.
A bamboo grid or a fiber net is placed over thatched roof or iron sheet covering and tied to the purlins or to another anchoring device.

VULNERABILITY REDUCTION

Both systems prevent tearing out of the roof covering during cyclones and strong winds. Even if some parts of the covering may be displaced, they will not be blown off.

REMARKS

- These systems are often associated to other technical solutions and devices (such as 4-slopes roof shape, anchoring systems, etc.). All together they contribute to considerably reducing the vulnerability of the whole construction or some of its parts to strong winds.
- These systems use very cheap, locally available and recycled materials, chosen according to the covering material.

1) South Korea: a traditional house with a fiber net covering the thatched roof in Jeju island

Bangladesh:
2) the air passes through the thatched roof avoiding blown off thanks to a bamboo grid;
3) tiles may move and be displaced but they will not be blown off as they are held in place by a recycled fishing net;
4) the iron sheet roofing is sandwiched between a bamboo grid and the purlins tied together;
5) double stabilization system over tiled roof

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

PRACTICE

ROOF COVERING VEGETABLE STABILIZATION

CONCERNED PARTS

Roof covering

PROBLEMS

Cover wrenching

LOCATION

Bangladesh: Barisal, Rajshahi
India: Odisha
Côte d'Ivoire

PRESENT & FUTURE APPLICATION

● Commonly known and applied

BRIEF DESCRIPTION

The roof is used as a support for climbing plants and creepers.

VULNERABILITY REDUCTION

Risk of wrenching as well as partial or total uplift is reduced as the plants fasten together the roof components thus helping to stabilize the cover.

1) Bangladesh: vegetable stabilization on thatched roof

REMARKS

- The plants stabilizing the roof usually provides vegetables and livelihood to the family.

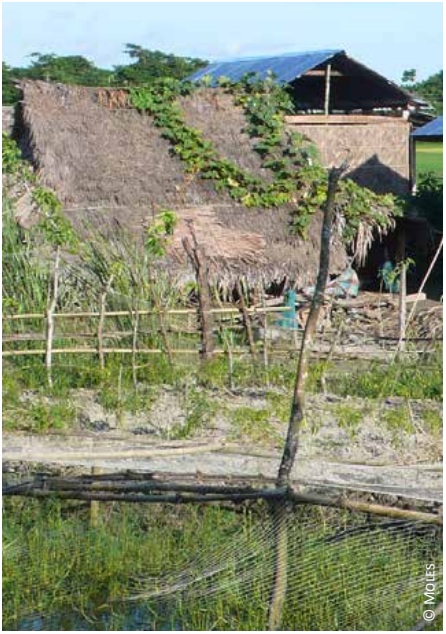
FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CAIMI, A. & HOFMANN, M. 2005. *From kutcha to pucca*. Master thesis. Lausanne: Swiss Federal Institute of Technology-EPFL.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

CORNET, L. 2013. *Boîte image: bonnes pratiques locales. Réduction de la vulnérabilité aux inondations des populations (et de leur cadre bâti) d'Afrique de l'Ouest et Centrale, Benin*. Villefontaine: IFRC, CRAterre.



Vegetable stabilization on thatched roof: 2) Ivory Coast; 3) Bangladesh

PRACTICE

ROOF COVERING FASTENING

CONCERNED PARTS	PROBLEMS
Roof covering	Cover wrenching
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Dinajpur, Khulna	● Commonly known and applied

BRIEF DESCRIPTION

Bamboos are placed above the roof covering and fastened to the roof structure or to bamboos placed under the covering.

For tiled roof, bamboo slats are arranged above the first lower rows of tiles and fastened to the roof structure with a rope passing through holes drilled in the tiles.

VULNERABILITY REDUCTION

Risk of roof wrenching is reduced, minimizing displacements and preventing tearing off. On tiled roof, fastening prevents uplift of the lower rows that are the most exposed to wind pressure during cyclones and strong winds.

REMARKS

- Whole bamboos are generally used for light panel covering (such as CGI sheets), while for tiled roof slats are more common.

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

Bangladesh: 1) bamboo slice placed over the lower row of tiles and fastened to the purlins; 2) bamboos placed over iron sheet roof and fastened to the purlins

Bangladesh: 3 & 4) bamboo slices are placed over the tiles and fastened to the purlins with ropes passing through holes drilled in the tiles

TECHNIQUE

WINDBREAK FASCIA AND BARGEBOARD

CONCERNED PARTS	PROBLEMS
Roof covering	Cover wrenching

LOCATION	PRESENT & FUTURE APPLICATION
Haiti: West and South-East departments, Antilles, Bangladesh, La Reunion	● At risk

BRIEF DESCRIPTION

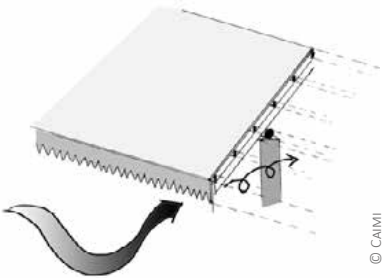
Serrated and perforated wooden fascia boards are placed at the edge of the roof panels, running on all sides of the building.

VULNERABILITY REDUCTION

The decoration breaks the wind flow generating eddies. High pressures likely to tear off the roof covering are minimized and local breakout forces are reduced.

Windbreak fascia and bargeboards:
1) La Reunion;
2) Haiti, rural area

Windbreak fascia board:
3) Haiti, gingerbred house in urban area;
4) windbreak system



REMARKS

- This device is used on iron sheet roofs, in many cases, only on the more exposed sides of the building.
- In Haiti, it has been observed on several houses in rural areas as well as on some old urban buildings. Its application is still quite widespread in rural areas, but it may decrease in the future because of wood shortage and loss of knowledge about its function.

FIND OUT MORE

BARRÉ, C. DE LA FOYE, A. MOREAU, S. 2011. C*onception paracyclonique. À l'usage des architectes et ingénieurs*. Villefontaine: Les Grands Ateliers de l'Isle d'Abeau.

CAIMI, A. GUILLAUD, H. MOLES, O. et al., 2013. « Traditional and scientific knowledge for a sustainable vulnerability reduction of rural housing in Haiti ». In: *Structures and Architecture: Concepts, Applications and Challenges*. Guimarães: CRC Press / Taylor & Francis, 2013. p. 1807-1815.

BERTHELOT, J. & GUAUME, M. 2002. *Kaz antiyé jan moun ka rété. L'habitat populaire aux Antilles*. Goyave: Editions perspectives creoles.

TECHNIQUE

EXTENDED ATTIC FOR ROOF STABILIZATION

CONCERNED PARTS

Roof structure and covering

PROBLEMS

Roof blowing off

LOCATION

Haiti: West, South-East and North-West departments

PRESENT & FUTURE APPLICATION

● Commonly known and applied

Haiti, extended attic with different types of roof: 1) thatched roof, 2) gable roof with a small window for external access, 3) 4-sided roof

BRIEF DESCRIPTION

An attic is created with timber planks under the portion of the roof extended to create a veranda. In 2-slope roofs, a small window is generally built above the veranda.

VULNERABILITY REDUCTION

Both 2- and 4-slope roofs are generally built to cover the whole living space, including the veranda.

The part of the roof covering the veranda is very sensitive to strong winds and its uplifting can damage the whole roof. The extension of the attic to this portion of the roof prevents the wind from acting directly on the roof structure, reducing the risk of a complete blown off.

REMARKS

- This solution is applied on the whole length of the façade or just on a corner, according to the shape and location of the veranda.
- Horizontal bracing are sometimes placed in the ceiling plane, and contribute to enhancing the capacity of the building to withstand strong winds.
- Timber planks usually prevent the wind from uplifting the overhangs.

Haiti: 4) bracing in the attic plane; 5) timber planks prevent the wind from uplifting the overhangs

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

DEJEANT, F. 2013. *Mallette pédagogique pour l'amélioration des architectures rurales en structure porteuse en bois dans le departement du Sud-Est D'Haïti*. Villefontaine: CRAterre, UN-HABITAT, AECID.

TECHNIQUE

FLAT STONES EAVES

CONCERNED PARTS	PROBLEMS
Roof structure and covering	Structural dissociation
LOCATION	**PRESENT & FUTURE APPLICATION**
Nepal: Myagdi district	● At risk

BRIEF DESCRIPTION

Flat stones are used to build the eaves of low pitch (about 15%) 2-slope roofs and gable awnings. Slate used for covering the roof and the awnings are between 3-4 cm thick. The larger stones (80x60cm) are placed on the edge of the roof above the sidewalls; their size decreases approaching the ridge. The stones are laid without fixings and held in place by overlapping with larger flags above. Awnings and eaves form a continuous overhang (about 50cm deep) all around the building.

Nepal, after the 2015 M 7.8 Gorkha earthquake: 1) flat stone coping

VULNERABILITY REDUCTION

The overhang created by the awnings and the eaves provides improved stiffness and structural solidarity to the building.
The awnings reduce the slenderness of the gable walls.
The use of non fixed flat stones for the roof covering requires a low pitch roof; thereby, gables have limited height and are confined by the weight of the awnings and the roof covering.

REMARKS

- This type of roof is widespread in some areas of Nepal, but an increasing number of people are now using iron sheet roofing as it is easier to install. This change in practices may induce some vulnerability if compensation features are not applied (for example, in order to confine gable walls and reduce their slenderness).

FIND OUT MORE

FERREIRA MENDES, M. HOSTA, J. LE GALL, O. 2015. *Technical guide for master trainers: Earthquake resistant buildings using local materials in Dolakha, Ramechhap and Sindhuli - Nepal*. Grenoble: CRAterre, Nepal Red Cross Society, Swiss Red Cross.

Nepal, after the 2015 M 7.8 Gorkha earthquake: 2) roof covering

TECHNIQUE

DOUBLE SLOPE ROOF COVERING FOR WALL PROTECTION

CONCERNED PARTS	PROBLEMS
Roof covering, walls	Water erosion, moisture
LOCATION	**PRESENT & FUTURE APPLICATION**
Haiti: West department	● Commonly known and applied

BRIEF DESCRIPTION

The lower portion of the iron sheet roof (about 1/6 or 1/4 of its overall length) has a lower pitch angle than the upper portion. It ends with large overhanging elements. These overhangs are supported by fascia boards or by an additional structure.

VULNERABILITY REDUCTION

The difference of slope provides a projection directing rain water away from the wall, limiting its erosion due to a direct exposure and splashing back.
By diverting the water away from the house, moisture affecting the lower part of the structure is also reduced.
This device improves the protection of the wall while limiting the extension of the overhangs, vulnerable to strong winds.

Haiti: double slope on 1) gable roof and 2) 4-slope roof

REMARKS

- This device is applied on both 2- and 4-slope roofs.
- The change in slope also contributes to reducing the risk of roof blowing off.

FIND OUT MORE

BARRÉ, C. DE LA FOYE, A. MOREAU, S. 2011. *Conception paracyclonique. À l'usage des architectes et ingénieurs*. Villefontaine: Les Grands Ateliers de l'Isle d'Abeau.

BELINGA NKO'O, C. 2011. *Haïti. Programme de reconstruction de l'habitat rural par les organisations de la PADED-Plateforme Agroécologique et dévloppement Durable*. Mission report. Port-au-Prince: Misereor.

Haiti: 3) water evacuation away from the house

PRACTICE

BAMBOO GUTTER

CONCERNED PARTS

Roof covering

PROBLEMS

Degradation of the bottom part of the structure, ground moisture

LOCATION

Philippines: Aklan Province

PRESENT & FUTURE APPLICATION

● At risk

BRIEF DESCRIPTION

A half bamboo is tied horizontally at the bottom part of the roof, on each side.

VULNERABILITY REDUCTION

The gutter collects the rain water from the roof and redirects it away from the building in order to avoid excess of water near the building that may causes instability of the structure and accelerate the degradation of its lower parts (foundations, posts, walls).

Philippines: rainwater is redirected away from the building thanks to a bamboo gutter

REMARKS

- This device is very cheap and simple to install; once rotten, bamboo gutter can easily be replaced.
- The gutter is a good system to collect water, connecting it to a water tank or simply placing drums and jerrycans under the evacuation hole.
- A proper drainage shall be provided at the water evacuation point.

FIND OUT MORE

CAIMI, A. 2015. *Shelter and livelihood improvement project for the indigenous community of Aklan. recovery after typhoon Yolanda*. Mission report. November 2015. Kalibo: CRAterre.

PRACTICE

ANTI-TERMITE METAL BARRIER

CONCERNED PARTS	PROBLEMS
Main structure	Termites
LOCATION	**PRESENT & FUTURE APPLICATION**
Guinea-Bissau	● Commonly known and applied

BRIEF DESCRIPTION

Metal pieces are placed between the top of the wall and the roof structure.

VULNERABILITY REDUCTION

The contact surface between the wall and the roof structure is minimised in order to reduce the risk of termite attacks to the roof timber frame.
The metal pieces create a disconnection between the wall and the roof blocking the path to termites climbing up along the wall.

Guinea Bissau, anti-termite barrier: 1) curved metal piece; 2) recycled iron sheet; 3) hard wood

REMARKS

- Hard wood and small pieces of iron sheets discarded from other construction parts can also be used.

FIND OUT MORE

MOLES, O. 2015. *Projet de promotion d'un habitat durable au profit de familles vulnérables*. Mission report. Villefontaine: CRAterre, Fondation Abbé Pierre.

PRACTICE

CONICAL BUNDLES FOR LOCALIZED THATCH REPLACEMENT

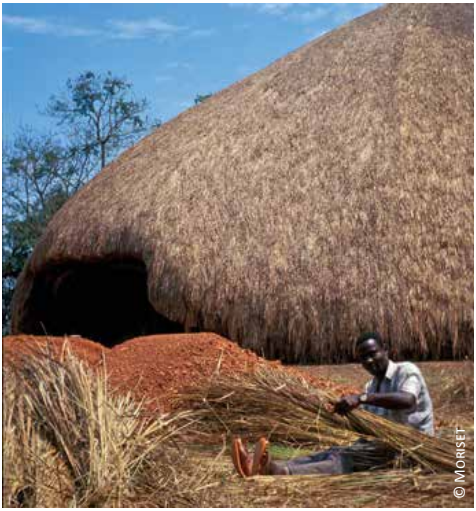
CONCERNED PARTS	PROBLEMS
Roof covering	Thatch deterioration
LOCATION	**PRESENT & FUTURE APPLICATION**
Uganda: Kampala, kingdom of Buganda	● Commonly known and applied

BRIEF DESCRIPTION

The grass for thatching is prepared in conical bundles which are simply laid onto the roof structure without being tied, except for the first layers at the bottom.

VULNERABILITY REDUCTION

When one bundle is rotten, it can be easily pulled out and replaced by driving another bundle at its place. This practice facilitates maintenance allowing for a fast and a very localized replacement of damaged parts.



Uganda: 1, 2 & 3) preparation of conical bundles

Uganda: 4, 5 & 6) localized replacement of damaged thatch portions

REMARKS

- This practice allows for an optimization of labour and materials for maintenance.
- The conical shape of the bundle facilitates its installation without affecting the bundles already in place.
- As additional measure to improve the durability of the roof, small fires are lighted inside thatched buildings so that the grass is covered by a layer of soot reducing the risk of termite attacks.

FIND OUT MORE

MORISET, S. 2006 & 2011. *Kasubi tombs. Uganda, Kampala*. Villefontaine: CRAterre-ENSAG.

Philippines:
a rural house rebuilt after 2013 typhoon Hayan

SECONDARY ELEMENTS

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TECHNIQUE

WALL DISCONNECTION FROM THE GROUND

CONCERNED PARTS

Wall fences

PROBLEMS

Water erosion, ground moisture

LOCATION

Bangladesh: Barisal, Dinajpur, Mymensingh

PRESENT & FUTURE APPLICATION

● Commonly known and applied

BRIEF DESCRIPTION

A gap of about 5 to 15 cm is left between the ground and the lower part of the wall fences.

VULNERABILITY REDUCTION

The disconnection between the wall and the ground avoids rising damp coming from the soil, increasing the lifespan of the fences.

Bangladesh: 1) gap under bamboo walling; 2) gap all around the house; 3) infill of the gap on the inside under fence frame

REMARKS

- On the inside, the gap can be closed with burnt bricks or other damp proof materials in order to avoid animals getting inside and to provide an additional support for the wall frame.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

TECHNIQUE

FLEXIBLE AND LIGHT GABLE FACADE

CONCERNED PARTS	PROBLEMS
Walls	Wall collapse
LOCATION	**CURRENT & FUTURE APPLICATION**
Iran	● Not applied anymore

BRIEF DESCRIPTION

Façades made of wood and glass usually close winter living spaces in traditional Qajar houses (Iran).

VULNERABILITY REDUCTION

Gable-end walls are often the first to collapse in case of an earthquake because they are usually slightly linked to the rest of the structure and have a high slenderness ratio. Closing vaulted rooms with a light and flexible facade is thus a solution to avoid the collapse of heavy walls in case of out-of-plan quake.

REMARKS

- This kind of facade allows for efficient natural lighting of indoor spaces and an increase in passive solar gain during winter.

FIND OUT MORE

CRÉTÉ, E. 2016. *L'architecture en terre crue face aux catastrophes : oubli des stratégies traditionnelles et enjeux en période de reconstruction*. Mémoire du DSA Terre. Grenoble: École Nationale Supérieure d'Architecture de Grenoble.

Iran: traditional Qajar house in Yazd

TECHNIQUE

WALL DIVISION INTO PANELS

CONCERNED PARTS	PROBLEMS
Wall fences	Fence wrenching
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Barisal, Chittagong, Dhaka	● Commonly known and applied

BRIEF DESCRIPTION

Lightweight wall fences are subdivided into several panels by a non load-bearing timber frame.

VULNERABILITY REDUCTION

The timber frame increases the stiffness of the fences, reducing the risk of wrenching under strong wind pressure.

Bangladesh: 1) iron sheet panelled fences; 2) carved wooden panels in the fence upper part for improved ventilation

REMARKS

- In case of damage, only affected panels can be replaced instead of rebuilding the whole frontage, reducing maintenance and repairing costs.

FIND OUT MORE

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

Bangladesh: 3) plywood panels

TECHNIQUE

MULTI-PART WALL FENCES

CONCERNED PARTS	PROBLEMS
Wall fences	Damage to parts exposed to water
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Barisal, Chittagong, Dinajpur, Mymensingh	● Commonly known and applied

BRIEF DESCRIPTION

The total height of the wall fence is subdivided in 2 or more panels using the same or different types of lightweight materials (such as iron sheets, bamboo or reed woven mats).

Bangladesh: 1 & 2) three-parts wall fence: CGI sheet on the bottom part, thick bamboo woven mat in the middle and thinner bamboo woven mat on the top of the wall

VULNERABILITY REDUCTION

This solution allows for easy and low-cost maintenance of the wall as only the lower panel is replaced, once the bottom part of the fence is damaged.
In some cases, iron sheets are used in the lower part of the walls as they are more resistant to moisture. Since it is an expensive material and in order to avoid over heating of the room, it is used only for the panels nearer to the ground.

REMARKS

- Different textures are sometimes used: a thicker one for the middle panel to ensure privacy, and a thinner one for the upper par of the wall providing indoor ventilation.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

Bangladesh:
3) double jute stick panel

PRACTICE

VEGETABLE DOUBLE-SKIN PROTECTION

CONCERNED PARTS	PROBLEMS
Walls	Wall degradation, water erosion
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Khulna	● Commonly known and applied

BRIEF DESCRIPTION

Panels of woven leaves with a bamboo structure are placed at about 40 to 60 cm from the wall on the sides of the building that are more exposed to rain water and prevailing winds.

VULNERABILITY REDUCTION

The panels protect the earthen walls from erosion and degradation due to direct exposure to rain and strong winds. Maintenance cost and work are thus reduced as the lifespan of the wall is increased and the panels can be easily replaced using freely available materials.

Bangladesh, vegetable double-skin: 1) covering the whole façade; 2) gap ensuring the ventilation of the wall

The gap between the wall and the panels prevents the rainy water from affecting the earthen wall and allow for an air flow thus avoiding moisture.

REMARKS

- The vegetable double-skin system is also used for improving the comfort inside the house. The shade provided by the panels and the gap between the panels and the wall cool down the earthen wall keeping a comfortable temperature inside the house.
- The panels are also used to protect outside covered spaces (such as the veranda) from water during rainy season.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

3) Bangladesh: vegetable panels reducing heat in the living spaces

TECHNIQUE

PERFORATED PANELS FOR WIND PRESSURE CONTROL

CONCERNED PARTS	PROBLEMS
Openings	Inside pressure, roof wrenching
LOCATION	**PRESENT & FUTURE APPLICATION**
Haiti: West and South-East departments	● At risk

BRIEF DESCRIPTION

Serrated and perforated wooden boards are placed above the openings (localized friezes) or between the roof and the upper part of the wall all around the building, forming a continuous frieze.

VULNERABILITY REDUCTION

The friezes work as a control system for the pressure inside the building during strong winds and cyclones. As the frieze is permeable, the wind can enter inside the building but it can also easily find a way out. This contributes to balancing the inside and outside pressure reducing the risk of wrenching of the roof structure and the covering.

Haiti: 1) continuous frieze running along all the façades; 2) localized frieze above a window

REMARKS

- This device is particularly effective for iron sheet roofing as the whole roof may be blown off due to inside pressure.
- This system allows for ventilation and lightening even when all the other openings are shut down, contributing to a good indoor comfort in hot and humid climate regions.
- Localized friezes placed on opposite walls are more effective than on adjacent walls as they provide a direct way in and out.
- The thin carving ensures privacy and reduces the risk of thieves and animals getting inside.

FIND OUT MORE

BARRÉ, C. DE LA FOYE, A. MOREAU, S. 2011. *Conception paracyclonique. À l'usage des architectes et ingénieurs*. Villefontaine: Les Grands Ateliers de l'Isle d'Abeau.

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

Haiti: 3) perforated panels above the windows and on the upper part of the gable end wall of a house rebuilt after 2010 earthquake

PRACTICE

PLASTIC BOTTLE ANTI-RIP

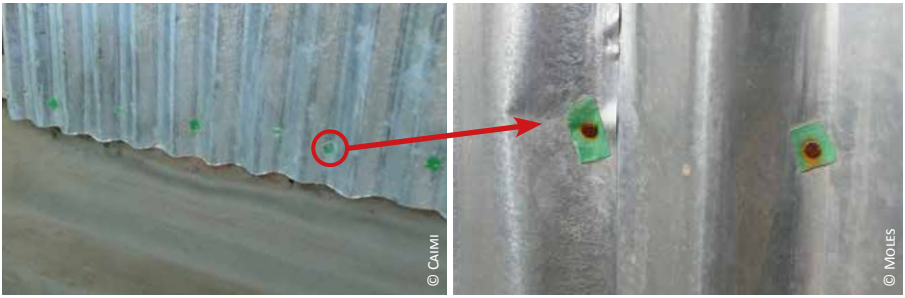
CONCERNED PARTS	PROBLEMS
Wall fences	Iron sheet wrenching
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Dinajpur	● Commonly known and applied

BRIEF DESCRIPTION

When iron sheets are used for wall fencing, a small piece of plastic recycled from used bottle or other items is placed between the head of the nail and the iron sheet.

VULNERABILITY REDUCTION

The plastic piece works as anti-rip reinforcement avoiding the piercing of the iron sheet by the nails under wind pressure, and so reducing the risk of wrenching of the fence.



Bangladesh: 1 & 2) plastic anti-rip regularly placed for each nail

REMARKS

- This solution is very cheap as the plastic pieces can be easily obtained from plastic bottles and jerrycans that are no longer used for other purposes.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

TECHNIQUE

DOOR BRACING

CONCERNED PARTS

Openings

PROBLEMS

Frame and/or shutter deformations

LOCATION

Bangladesh

PRESENT & FUTURE APPLICATION

● At risk

BRIEF DESCRIPTION

Diagonal elements are placed on shutters of doors and windows.

VULNERABILITY REDUCTION

Bracing limits door twisting and deformation under pressure of strong winds or lateral loads induced by an earthquake, so that it can be properly closed and people do not get trapped inside.

Bangladesh: bracing on timber door shutter

REMARKS

- Bracing of the frame of door shutter can also be done when using bamboo and woven mats.

FIND OUT MORE

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh.* Villefontaine: CRAterre.

TECHNIQUE

DOUBLE STRUCTURAL FRAME FOR WALL OPENINGS

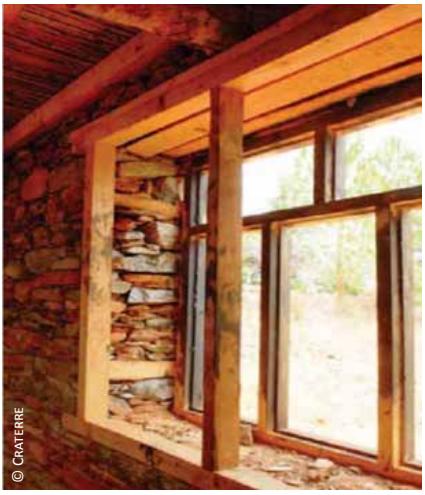
CONCERNED PARTS	PROBLEMS
Openings	Structural failure
LOCATION	**PRESENT & FUTURE APPLICATION**
Nepal: Dolakha, Ramechhap, Sindhuli districts Turkey	● At risk

BRIEF DESCRIPTION

Doors and windows have a double timber frame placed on the two sides of the masonry wall and connected by wooden horizontal pieces.

VULNERABILITY REDUCTION

The connected double frame acts as a box providing an additional support for the above portions of the wall as well as for the upper stories or the roof in case of structural weakening of the masonry walls during earthquakes.



Nepal: 1) a window with a double timber frame; 2) the double frame of a window supporting the roof after the failure of a masonry wall during 2015 Gorkha earthquake

REMARKS

- The double frame of windows and doors limits the falling down of stones and provides occupants with a safer way for escaping.

FIND OUT MORE

FERREIRA MENDES, M. 2015. *Support for the Swiss Red Cross for reconstruction in Nepal*. Mission report. Villefontaine: CRAterre.

HOFMANN, M. 2015. *Le facteur séisme dans l'architecture vernaculaire. Un décryptage entre determinants culturels, types de structures et ressources cognitives parasismiques*. PhD thesis. Lausanne: Swiss Federal Institute of Technology.

PRACTICE

FURNITURE INTEGRATED TO THE WALLS

CONCERNED PARTS	PROBLEMS
Furniture	Furniture overturning
LOCATION	**CURRENT & FUTURE APPLICATION**
Iran: Yazd	● Not applied anymore

BRIEF DESCRIPTION

Alcoves are a wide-spread architectural element in yazdi traditional architecture. People used to take advantage of the important thickness of the first floor walls to create immovable storage units between buttresses.

VULNERABILITY REDUCTION

The alcove allows for storing items without risking cupboard overturning.

REMARKS

- Alcoves became a major esthetical element. They are sometimes reduced to a dozen cm deep and made out of plasters and no longer structurally linked to the walls.

FIND OUT MORE

CRÉTÉ, E. 2016. *L'architecture en terre crue face aux catastrophes : oubli des stratégies traditionnelles et enjeux en période de reconstruction*. Mémoire du DSA Terre. Grenoble: École Nationale Supérieure d'Architecture de Grenoble.

Iran: cupboards between buttresses in a yazdi house

PRACTICE

RAISED PLATFORM

CONCERNED PARTS

Platform, mezzanine

PROBLEMS

Water penetration inside the house

LOCATION

Bangladesh: Dhaka, Dinajpur, Sylhet

PRESENT & FUTURE APPLICATION

● Commonly known and applied

BRIEF DESCRIPTION

Inside the house, indoor furniture and/or special platforms are raised above the ground level.

VULNERABILITY REDUCTION

Furniture and raised platforms provide elevated places for keeping safe the goods and for people to stay above the water level during floods.

Bangladesh: 1) raised furniture; 2) closed space elevated on a platform where people take shelter during floods

REMARKS

- In some cases, closed platforms are built inside the house for storing the food and for people to be protected from snakes during floods.
- Furniture and raised platform sometimes take up a lot of space indoors. However, this is generally in line with people daily life, as inhabitants usually use the platforms for sleeping and sitting.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh.* Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh.* Villefontaine: CRAterre.

PRACTICE

ELEVATED MEZZANINE

CONCERNED PARTS	PROBLEMS
Platform, mezzanine	High water level
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Dinajpur, Mymensingh	● Commonly known and applied

BRIEF DESCRIPTION

Elevated light platforms are built using bamboos and woven mats inside the house as attics or outside under the roof eaves.

VULNERABILITY REDUCTION

Goods, food and wood for cooking are kept safe from rising water during floods.

Bangladesh: 1) indoor mezzanine under the roof; 2) outdoor mezzanine under roof eaves

REMARKS

- This system is very effective and cheap as leftover material can be used to build the platform.
- The reduced weight of the mezzanine does not affect the main structure.
- In normal time, the platforms are used as storage spaces and sometimes as sleeping space for kids.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

PRACTICE

WATER BARRIER ON DOOR SILL

CONCERNED PARTS

Openings, doors

PROBLEMS

Water penetration

LOCATION

Bangladesh: Sylhet; Haiti: North West department; Italy : Venice

PRESENT & FUTURE APPLICATION

● Commonly known and applied

BRIEF DESCRIPTION

Fixed or removable barriers are placed on the door sill using different materials: wood planks, small masonry works, etc.

VULNERABILITY REDUCTION

During high floods, the barrier prevents the water from getting inside the house through the door. The height of the barrier is generally the one of the ordinary floods.

REMARKS

- This system is effective during small-scale floods and/or associated to a platform elevating the whole building from the ground level.

FIND OUT MORE

CAIMI, A. 2014. *Cultures constructives vernaculaires et résilience*. PhD Thesis. Grenoble: University of Grenoble.

CORNET, L. 2015. *Assessed good practices and technical solutions for construction resilience and durability in Bangladesh*. Villefontaine: CRAterre.

1) Italy, Venice: removable metal barrier; 2) Bangladesh: removable timber barrier; 3) Haiti: fixed masonry barrier

Vietnam :
thatched houses in Ha Thanh

ENVIRONMENT

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Cyclones Practice South Korea

PRACTICE

HOUSE RELOCATION

CONCERNED PARTS	PROBLEMS
Overall structure	Vulnerable sites
LOCATION	**PRESENT & FUTURE APPLICATION**
Philippines: Aklan province	● Commonly known and applied

BRIEF DESCRIPTION

An existing house is relocated through traditional community help (called *bayanihan*). The whole house is moved without dismantling. Volunteers from the community get together and lift up the house using the existing stilt structure or long bamboo poles placed length-wise and cross-wise under the house. The house is then carried by hand and settled on a new site.

1) Philippines: house relocation using bamboo poles

VULNERABILITY REDUCTION

Relocation of the house generally occurs when the site is exposed to floods during heavy rain and storm season. Moving the house on a safer site directly reduces the building vulnerability as well as risks for their occupants.

REMARKS

- This practice is possible as the houses do not have fixed foundations: they are built on stilts with the main posts relying on stones or directly driven into the ground.
- Relocation may also occur when the house owner does not own the land where the house is built.

FIND OUT MORE

CAIMI, A. 2015. *Shelter and livelihood improvement project for the indigenous communities of Aklan, Philippines. Recovery after typhoon Yolanda.* Mission report. Kalibo: CRAterre, DSAC-Kalibo, Secours Catholique-Caritas France, Caritas International Belgium.

wikipedia.org/wiki/Communal_work

2) Philippines: house relocation using the existing structure of the house

PRACTICE

AERODYNAMIC SETTLEMENT PATTERN

CONCERNED PARTS	PROBLEMS
Settlement	Direct exposure to wind
LOCATION	**CURRENT & FUTURE APPLICATION**
Indonesia: Lombok	● At risk

BRIEF DESCRIPTION

Houses are packed on the top of a low hill. Streets are narrow and sinuous. Public buildings are found in the very center of the village. Their roof slopes are more important than the smallest buildings on the outskirts.

VULNERABILITY REDUCTION

The shapes of the roofs improve the buildings resistance towards strong winds. Moreover, the outer buildings act as a wind barrier and protect the inner ones. Hence, inhabitants often use the public buildings in the very center of the village as cyclone shelters.

Lombok:
1) the village aerodynamic shape,
2) the roof aerodynamic shape and the sinuous and narrow public spaces

PRACTICE

MASSIVE SETTLEMENT WALL

CONCERNED PARTS

Settlement

PROBLEMS

Wall collapse

LOCATION

China: Fujian

CURRENT & FUTURE APPLICATION

● Not applied anymore

China: a Tulou settlement

BRIEF DESCRIPTION

Hakka people used to organize their settlements in *Tulou* in Fujian, China. Those massive structures consist in a peripheral rammed earth wall (round or square) that supports a wooden inner structure. They usually are app. 20 m high and can host up to 800 inhabitants. *Fuxing tulou* dates back to 800 AD.

VULNERABILITY REDUCTION

Tulou peripheral wall is a stiff structure with very few openings and a regular shape. The wall thickness decreases as it elevates and it is usually reinforced with wooden or bamboo insertions. These elements are highly favourable to a good seismic behaviour.

REMARKS

- *Tulou* were built for defence purposes which partly explain that particular attention was paid to their resistance to lateral forces.

FIND OUT MORE

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PRACTICE

ELEVATED PATH

CONCERNED PARTS	PROBLEMS
Pedestrial paths	Flooded lands
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Sylhet Senegal: Dakar	● Commonly known and applied

BRIEF DESCRIPTION

Different materials (stones, used tyres, bricks, used cement bags) are used to create an elevated path to access the house or to move in the streets.

VULNERABILITY REDUCTION

During floods, the elevated path allows for people to move around protected from water. The level of the path is generally a little bit higher than the ordinary flood level.

REMARKS

- The materials used are generally very cheap as they are freely available, leftover or recycled materials.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

SEVILLANO GUTIERREZ, E. 2010. *Équipe de lutte contre les inondations. Hivernage 2010*. Dakar: Mouvement International ATD Quart Monde.

Senegal, during floods: 1) used tyres and 2) sandbags path for moving in the street; 3) stone path to access the house 4) Bangladesh: brick path during dry season

PRACTICE

WAVE BREAKER

CONCERNED PARTS	PROBLEMS
River banks	River bank erosion
LOCATION	**PRESENT & FUTURE APPLICATION**
Bangladesh: Mymensingh	● Commonly known and applied

BRIEF DESCRIPTION

A bamboo grid is built on riverbanks exposed to erosion.

VULNERABILITY REDUCTION

The bamboo grid works as wave breaker during floods when the river current becomes very strong. Placed diagonally to the river, it breaks the water flow preventing soil erosion and failure of embankments. Its height is related to the normal flood level.

REMARKS

- The bamboo grid is built using locally available and cheap materials (such as bamboos, coconut fibre ropes) allowing for a easy and low-cost maintenance by local people.

FIND OUT MORE

CAIMI, A. 2012. *Construction of Pilot Low Cost Houses (LCH) Project for the Disaster Affected families of Bangladesh*. Mission report. Dhaka: CRAterre.

Bangladesh: wave breaker bamboo grid during low level season

PRACTICE

LIVING TIMBER POLE PALISADE

CONCERNED PARTS

Unstable slopes

PROBLEMS

Landslides, soil erosion

LOCATION

Philippines: Aklan province

PRESENT & FUTURE APPLICATION

● Commonly known and applied

BRIEF DESCRIPTION

Fresh cut branches are vertically driven into the soil in a line. Timber planks or fresh cut branches are then placed horizontally on the upstream side of the poles.

VULNERABILITY REDUCTION

The living branches sprout very quickly and their roots grow stabilizing the slope in a durable manner.

REMARKS

- This solution is effective and very cheap.
- Depending on the species of the tree, it may take a long time before the palisade is effective. Temporary soil stabilization has to be provided.
- In areas prone to cyclones and strong winds, the palisade shall be placed to a sufficient distance from buildings in order to avoid damage from uprooted or falling parts of the trees.

FIND OUT MORE

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SHAH, B. H. 2008. *Field manual on slope stabilization*. Islamabad: UNDP.

Philippines: sprouted posts of a small palisade only few days after planting

PRACTICE

VETIVER SOIL STABILIZATION

CONCERNED PARTS	PROBLEMS
Unstable slopes, river banks, embankments	Landslides, soil erosion

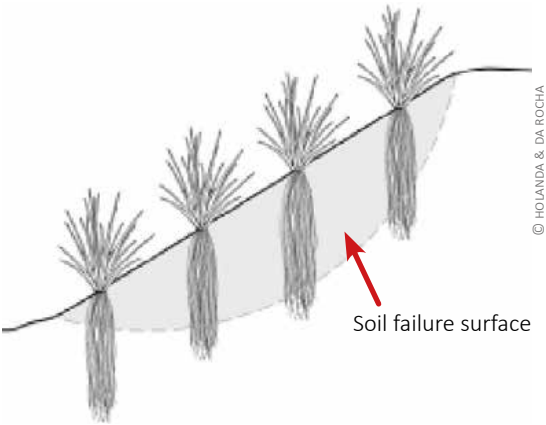
LOCATION	PRESENT & FUTURE APPLICATION
Bangladesh: Mymensingh	● Commonly known and applied

BRIEF DESCRIPTION

Vetiver grass rows are planted on riverbanks or steep and unstable slopes vulnerable to erosion.

VULNERABILITY REDUCTION

Vetiver grass has extremely deep and massive finely structured roots, capable of reaching down to 2 to 3m during the first year of growth. This extensive and thick root system binds the soil and, at the same time, makes it very difficult to be dislodged providing a good anchor for fill and topsoil.



1) Soil reinforcement by vetiver grass roots minimizing erosion risks

REMARKS

- Vetiver grass tolerates well extreme climatic and environmental variation, including prolonged drought, flooding and submergence.
- Per unit area vetiver roots are stronger than tree roots.
- When planted in rows, vetiver plants create thick hedges forming a living barrier which slows and spreads runoff water diverting it to stable areas.

FIND OUT MORE

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2) Bangladesh: vetiver plantation to protect the embankment from erosion during recurrent floods

PRACTICE

WIND SCREENING COMPOUND WALLS

CONCERNED PARTS

Compound walls

PROBLEMS

Wall overturning

LOCATION

South Korea: Jeju

CURRENT & FUTURE APPLICATION

● Not applied anymore

BRIEF DESCRIPTION

Traditional houses are low and surrounded by porous compound walls made of volcanic stones (basalt).

VULNERABILITY REDUCTION / HYPOTHESIS

The walls that are built with volcanic stones are very porous and act as wind screens: they break the wind flow but do not block it so that the risk of overturning is limited.

Jeju island: 1) & 2) compound walls protecting low houses

REMARKS

- Along with this technique, one can observe other features that reduce the habitat vulnerability to strong winds, for example:
- buildings are low and covered by a roof with an aerodynamic shape;
- thatch roofs are covered by a net which is anchored into the main structure;
- the house walls are also built with basalt, sometimes plastered with earth to reduce porosity.

FIND OUT MORE

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China:
a *tulou* settlement

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WEBSITES & RESOURCES OF RELEVANT PROJECTS WORLDWIDE

Conservation Tech
www.conservationtech.com

CRAterre - International Centre for Earthen Construction
www.*craterre.org*

IFRC- International Federation of Red Cross and Red Crescent Societies
www.ifrc.org

NIKER- New integrated knowledge based approaches to the protection of cultural heritage from earthquake-induced risks :
www.niker.eu

Secours Catholique-Caritas France
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BASE ISOLATION FOR STRUCTURAL FRAME: Annalisa Caimi
SACRIFICIAL POST: Annalisa Caimi, Olivier Moles, Enrique Sevillano Gutiérrez
POST ISOLATION FROM THE GROUND: Annalisa Caimi, Olivier Moles

Main structure

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MULTI-PART WALL FENCES: Annalisa CAIMI, Olivier MOLES
VEGETABLE DOUBLE-SKIN PROTECTION: Annalisa CAIMI, Olivier MOLES
PERFORATED PANELS FOR WIND PRESSURE CONTROL: Annalisa CAIMI, Olivier MOLES
PLASTIC BOTTLE ANTI-RIP: Annalisa CAIMI, Olivier MOLES
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LIVING TIMBER POLE PALISADE: Annalisa CAIMI
VETIVER SOIL STABILIZATION: Annalisa CAIMI
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Nepal:
a settlement in stone masonry
with regular timber bands

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The IFRC supports Red Cross and Red Crescent National Societies in the areas of risk reduction through safer construction practices and sustainable construction of human settlements both before and after disasters. In addition, the IFRC is co-lead of the Global Shelter Cluster, tasked to coordinate the shelter response after natural disasters. IFRC considers that shelter construction is not just a matter of building a 'product' – but rather a 'process' whereby people can improve their own homes, and engage to create a safe and secure environment.
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CRAterre is working towards proposing valid responses to the global housing challenges while addressing the need for adaptation to climate change, the preservation of cultural diversity and the fight against poverty. To this end, CRAterre has a double status of research laboratory and NGO that allows to set a multidisciplinary team of researchers, professionals, lecturers and trainers that collaborate with many partners al around the world to establish creative links between academic research, on-the-field activities, training, knowledge dissemination and sensitization activities.
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This booklet has been prepared by CRAterre, IFRC and SC-CF and several of their partners. It is part of a set of tools now developed within the framework of a working group (leaded by CARE and CRAterre) within the Global Shelter Cluster to enhance the appreciation of local practices developed by communities to adapt their housing / settlements to their specific environment, including risk preparedness. It presents a series of worldwide examples of local techniques, know-how and knowledge that can be used in reducing housing vulnerability. Though, rather than being a catalogue, it has been conceived as an eye-opener for field operators. The idea is that, with these examples in mind, they will have a sharpened capacity to identify such local solutions during preliminary field inspections.

With basic information on why and how these practices are relevant, it is expected that at least those with higher potential are fully reused in habitat projects, both in post disaster and preparedness situations. These solutions being local, they can be implemented with local resources and so, offer large potential for wide application. Overall, that process gives more chance to provide durable benefits and enhanced resilience capacity for local communities while making sure that the qualities of local architecture are preserved. Moreover, it is also hoped that the scientific community will be encouraged to work on their understanding and retro-engineering for adaptation to today's socio-economic, cultural and environmental context so as to go further in building back safer processes towards more efficiency in recovery and further, sustainable development.

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